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Increasing the Productivity of the Nation's Urban Transportation Infrastructure

Measures to Increase Transit Use and Carpooling

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Increasing the Productivity of the Nation's Urban Transportation Infrastructure: Measures to Increase Transit Use and Carpooling:

An Executive Summary

This report surveys the growing use of bus and carpool priority measures to increase the productivity of the nation's transportation infrastructure. While it identifies a wide variety of priority measures, the report principally focuses on the planning and operation of exclusive and shared busways and high occupancy vehicle (HOV) facilities.

Chapters 3-10 present detailed case studies describing the implementation of exclusive busways, transitways, and other bus and carpool priority schemes in seven North American metropolitan areas (New York, San Francisco-Oakland, Ottawa-Carleton, Pittsburgh, Washington, D.C., Los Angeles-Long Beach-Orange County, and Houston). Chapter 2 provides less extensive evaluations of schemes implemented in other areas. Chapters 14 and 15 compare the cost-effectiveness of exclusive busways and bus-HOV facilities with the cost-effectiveness of recently completed light and heavy rail lines. Finally, Chapters 11-13 consider the problems of serving large downtown areas, something that many observers view as the Achilles heel of all-bus systems.

Exploiting Water Barriers

This survey of operational bus-carpool priority schemes demonstrates once again that necessity is the mother of invention. Some of the earliest, and still most effective, bus and carpool priority schemes were implemented at bridge and tunnel approaches in the New York, San Francisco-Oakland, and Vancouver metropolitan areas, where the prohibitive expense of providing additional water crossings prompted transport planners to consider innovative and low capital cost ways of increasing the passenger capacity of these critical facilities. As we discuss in the body of the report, these measures include both toll exemptions and discounts for buses and or carpools, and short queue jumpers that allow buses to bypass the heavy congestion that invariably occurs at the approaches to these facilities.

The New York metropolitan area has the most extensive facilities of this kind; six bus-carpool priority schemes serve 121,000 daily bus commuters to Manhattan during the three hour morning peak period. The most important of these, the four mile long XBL contra-flow-Lincoln Tunnel scheme, currently accommodates about 1,900 inbound buses and 69,000 inbound bus person trips per day.

Cost Effectiveness

Chapters 14 and 15 of the report provide strong confirmation of the findings of earlier scholarly studies of the comparative costs of alternative high performance transit modes. They demonstrate that exclusive busways generally have lower capital and operating costs than light or heavy rail systems and provide comparable or better levels of service.

The problem with both busways and light and heavy rail systems in most applications in North America is that existing levels of transit demand require only a small fraction of available right-of-way capacity. Nothing can be done about this problem in the case of rail systems, but high performance bus systems can often be designed to allow buses to share this excess capacity with other users, typically carpools and vanpools.

Both the El Monte Busway and the Shirley Highway operated for several years as exclusive busways. They were finally converted to bus-vanpool-carpool facilities when it became apparent that the numbers of buses required to serve existing and likely future transit riders required only a small fraction of busway capacity. Buses currently use less than 10 percent of the capacity of the Shirley Highway's two HOV lanes during peak hours; making the remaining unused capacity available to carpools and vanpools enables these lanes able to accommodate 2.2 times as many person trips per day as if only buses were allowed to use them.

Table ES-1 provides summary cost effectiveness measures for the El Monte Busway and the Shirley Highway, for operational segments of Houston's approved 95 mile transitway system, for commuter/diamond lanes in Virginia and California, for Ottawa's and Pittsburgh's exclusive busways, and for the recently completed light and heavy rail systems studied by Pickrell (1989).

Capital costs per daily transit round trip in 1989 dollars for the El Monte Busway and Shirley Highway HOV lanes are $16,260 and $8,868 respectively, as compared to $3,995 and

Table ES–1. Facility Length, Construction Costs, Daily Ridership, and Cost Per Mile and Per Round Trip for Transitways, Commuter Lanes, Exclusive Busways, and Light and Heavy Rail Systems

Facility	Miles	Daily Person Trips: Transit	Daily Person Trips: Total	Construction Costs (millions 1988 $'s): Total	Construction Costs (millions 1988 $'s): Mile	Construction Cost/ Round Trip: Transit	Construction Cost/ Round Trip: Total	Percent of LRT
Transitways								
El Monte Busway	11.0	13,221	43,000	$108.3	$9.8	$16,379	$5,036	13.2%
Shirley Highway	12.0	28,140	63,486	$122.9	$10.2	$8,735	$3,872	10.1%
Houston Transitways	36.6	21,479	42,420	$221.2	$6.0	$20,597	$10,429	27.2%
Commuter Lanes								
I–95, N. Va.	6.0	5,670	27,630	$5.6	$0.9	$1,975	$405	1.1%
Rte 91 S. Cal.	8.0	NA	19,102	$0.2	$0.03	NA	$21	0.1%
Exclusive Busways								
Ottawa	12.8	200,000	200,000	$388.0	$30.3	$3,880	$3,880	10.1%
Pittsburgh	10.8	47,000	47,000	$174.1	$16.1	$7,410	$7,410	19.3%
New Rail Systems								
Avg Heavy Rail	29.0	168,500	168,500	$3,329.5	$114.9	$39,519	$39,519	103.2%
Avg Light Rail	12.6	23,475	23,475	$449.5	$35.7	$38,296	$38,296	100.0%

Source: Table 17–2 of this report.

$7,470 for Ottawa's and Pittsburgh's exclusive busways. Including carpools and vanpools in the denominator reduces the average daily per round trip costs for the bus-HOV facilities by a large amount. At $4,999 and $3,931, the capital costs per total (buses plus carpools and vanpools) daily round trip of the El Monte Busway and the Shirley Highway HOV lanes are significantly less than the $7,470 per round trip capital cost of Pittsburgh's exclusive busways and close to the $3,995 per round trip capital cost attained by Ottawa's innovative exclusive busways.

The last (shaded) column in Table ES-1 reveals that the per round trip capital costs of the Ottawa and Pittsburgh exclusive busways are only 10.1 percent and 19.1 percent as large as those of the four recently completed light rail transit (LRT) systems studied by Pickrell (1989). Similarly, per round trip capital costs as a fraction of LRT costs for the three transitways shown in Table ES-1 vary from 10.1 percent in the case of the Shirley Highway to 27.2 percent for Houston's 36.6 miles of operational transitways. Use of the Houston transitways is expected to increase substantially as uncompleted segments of the Gulf and Northwest Transitways are opened. Somewhat surprisingly, the average per daily round trip capital costs in 1989 dollars of the eight light and heavy rail systems studied by Pickrell (1989), i.e. $39,038 and $40,285, differ by less than four percent.

What are variously referred to as commuter or diamond lanes fare even better when capital costs per daily round trip are used to measure cost-effectiveness. The incremental capital costs in 1989 dollars of the two commuter/diamond lane facilities shown in Table ES-1 are $413 per round trip for the I-95 diamond lanes in Northern Virginia and $23 per round trip for Southern California's Route 55 commuter lane.

As we discuss in Chapter 15, the critical term here is "incremental." Commuter/diamond lanes are primarily carpool lanes and serve relatively few transit trips; they are usually considered temporary facilities and plans frequently exist to replace them with more costly, physically segregated transitways at some future date. Commuter/diamond lanes, which are usually carved out of existing freeway right-of-ways by narrowing lanes, by eliminating or narrowing the medians and inside shoulders, and by similar measures, cost very little to build. The cost of providing these facilities consists principally of the opportunity costs of not using them as a general traffic lanes, and the adverse impacts on capacity, safety, and aesthetics of reducing original freeway design standards.

The Problems of Downtown Distribution

The problems of serving the CBDs of large cities are widely viewed as the Achilles heel of all bus systems, and the supposed inability of all bus systems to accommodate projected levels of transit use is a frequent justification for making the large capital expenditures required to build new light and heavy rail systems. Analyses included in this report demonstrate that while buses carry a large fraction of peak period person trips in the CBDs of large cities, they use relatively little CBD street space. Even the small amounts of street space used by buses, moreover, can be reduced by inexpensive changes in bus operations and by providing off-street bus facilities.

If further reductions in the bus use of CBD streets are desired, downtown people movers and bus tunnels can be used to augment CBD street space and to improve circulation within

downtown. While these solutions are less expensive than building an entire regional rail system, they are by no means cheap.

Built at costs of $178 million and $219 million (1989 dollars), recently completed downtown people movers in Miami and Detroit have been a disappointment to their supporters. They are currently carrying only about 11,000 riders a day each, and very few of these users are commuters

Bus tunnels are even more expensive. Seattle spent $371.8 million (1989 dollars) to build a 1.3 mile L shaped CBD bus tunnel. Ottawa, which is seriously considering building a CBD bus tunnel to replace the at-grade bus lanes that currently serve as the downtown link of its innovative exclusive busway system, estimates that the construction cost of its proposed bus tunnel will be similar to that of Seattle's bus tunnel.

Seattle's bus tunnel will not eliminate all buses from the CBDs surface streets anymore than building a light or heavy rail system would. The project's Final EIS found that the number of buses using CBD surface streets in 1990 would be 642 if the tunnel was built as contrasted to 488 if a transit mall was built instead.

Since the estimated construction costs for Seattle bus tunnel were $259.4 million (1989 dollars) greater than the estimated costs of a mall similar to Portland's operational transit mall, Seattle is spending about $1.7 million (1989 dollars) per bus for each of the 154 buses the tunnel would remove from the city's CBD streets in 1990. The capital cost per bus removed from downtown streets would be even greater if the projected capital costs of Seattle Non-Intercept Mall alternative, which seem high, are overstated.

Seattle's bus tunnel, which increasingly looks like a Trojan Horse for a coveted LRT system, will be equipped with tracks before it opens, even though there currently exists no "approved" rail plan for the region.

Acknowledgments

This study took over three years to complete, entailed field work in more than half a dozen metropolitan areas, and written correspondence and phone conversations with individuals in numerous others. As a result, an unusually large number of individuals contributed to the study. Indeed, this report could not have been completed without the willingness of dozens, if not hundreds of individuals, to give generously of both their time and their ideas. In identifying the individuals listed below we run the risk of failing to recognize many others who gave us advice, encouragement, ideas, and data. Nonetheless, we would be remiss if we did not make an effort to acknowledge those individuals whose help and cooperation have been instrumental in preparing this report. The individuals recognized in the following paragraphs are identified by their affiliation at the time the research was done and by the chapter where their contributions are most evident. Several, of course, contributed to more than one chapter.

The New York metropolitan area is a very large and complex place. Not surprisingly, as a result, an unusually large number of agencies and individuals provided data and other forms of assistance. These include Leon Goodman, Joan Konecnik, Joseph Leiper, and S. David Phraner of the Port Authority of New York and New Jersey; and Diane L. Gellman and Andrew Hollander of the New York City Department of Transportation.

Those providing hospitality and help during our visits to the San Francisco-Oakland Bay Area and in subsequent communications included Jeff Georgevich and Charles L. Purvis of the Metropolitan Transportation Commission (MTC); Gerald Robbins of the City of San Francisco Department of City and Regional Planning; Carl Natvig of the San Francisco Municipal Railway (MUNI); Peter Dyson, Warren L. Potts and Alan R. Zahradnik of the Golden Gate Bridge, Highway and Transportation District; and Franklin M. Lockfeld of the County of Santa Clara Planning Department.

OC Transpo's General Manager John A. Bonsall was a continual source of help and encouragement throughout the study. He supplied us with background materials before our visit to Ottawa; when we visited, he took the time to show and explain Ottawa's exclusive busway system to us, and to provide valuable background on its development. Finally, he reviewed and offered comments, made corrections, and provided suggestions for at least two drafts of Chapter 5.

Several individuals in Pittsburgh aided us in the preparation of Chapter 6 and commented on earlier drafts. These include Allen D. Biehler and Theodore C. Hardy of the Port Authority of Allegheny County (PAT); and Thomas C. Fox of the Commonwealth of Pennsylvania, Department of Transportation. We would like to especially thank Norman Voigt of PAT for the time he took to show us the Pittsburgh busways and the South Hills LRT and his careful explanations of their operations.

We did not make a site visit to Washington, D.C. The material included in Chapter 7 was thus culled from extensive secondary source materials. In addition, however, Bill Jeffrey and Carol Valentine of the Virginia Department of Transportation responded promptly to our numerous phone calls and letters, freely shared their data and insights, and showed great patience in answering our numerous questions.

Our Southern California case study required two chapters, Chapters 8 and 9. This reflects the large amount of information supplied by our confidants there. In this regard, we would like to acknowledge the help of Gail M. Jensen and Gary Moon of the Southern California Association of Governments (SCAG); Ron Klusza and Andrew M. Miceli of CalTrans, District 7; Larry W. Weseman of the Orange County Transit District (OCTD); and Donald G. Capelle of Parsons, Brinckerhoff, Quade & Douglas, consultants to OCTD.

The Houston case study reflects our fascination with and appreciation of both Houston's remarkable transitway system and the process that led to their development. We would like to take this opportunity to thank Jeff Arndt, Dan Barnes, Paul N. Bay, James A. Bunch, Bernard E. Calkins, Mark Charnews, Alan F. Kiepper, Robert C. Lanier, Robert MacLennan, John Sedlak, Douglas L. Wentworth, David Winfield, and Gordon D. Zwillenberg of the Metropolitan Transit Authority of Harris County (METRO). Dennis L. Christiansen, Tim Lomax, and William R. McCasland of the Texas Transportation Institute at Texas A & M; and Alan Clark of the Houston-Galveston Area Council (HGAC) for their help.

We visited Portland, Oregon and Denver, Colorado to view and collect data on their transit malls. We would like to thank our gracious hosts and those that supplied us with needed data both before and after our visits. At the Tri-County Metropolitan Transportation in Portland (TRI-MET), James C. Cowen and Ken Stanley were particular generous with their time. In Denver we were aided by Chester E. Colby, Steve Legler, Marilyn Cooks, Bill Hoople, Roger Mutz, and Yem Fong.

One of the most interesting and enjoyable aspects of the study was our visit to Seattle to view METRO's bus tunnel and to review the region's long history of HOV development. We would like to thank Greg Schweers of the Municipality of Metropolitan Seattle (METRO) and others whose names we are embarrassed to admit that we have forgotten. Joseph F. Conrad of the Washington State Department of Transportation and G. Scott Rutherford and Jerry Schieder at the University of Washington also provided data and helped us understand developments in the Seattle region.

On our trip to the West Coast we were also able to visit Vancouver to study their AGT system, transit mall, and extensive express bus operations, particularly their imaginative use of queue jumpers at the region's numerous bridges to provide bus priority. We would like to acknowledge the assistance of Glen Leicester and Clive Rock of BC Transit.

In addition to the preceding, our efforts were also aided considerably by John Hirton of Honolulu's Department of Transportation, John T. Ketelsen of Sacramento Regional Transit; John W. Billheimer of Systan, Inc.; William M. Lyons, TSC Section 15 Project Manager, Transportation Systems Center; Thomas E. Parody of Charles River Associates, Inc.; Earl R. Ruiter of Cambridge Systematics, Inc; and Frank Southworth of the Oak Ridge National Laboratory.

As always our efforts benefited greatly from the suggestions and insights of several of our friends and colleagues in Cambridge. In this regard, we would like to mention in particular Jose Gomez-Ibanez, Paul Kerin, John R. Meyer, and Don Pickrell.

Finally, we would be remiss if we failed to recognize the contribution of our UMTA project monitor, Joe Goodman, who was a valuable critic and showed great patience and understanding when we decided to expand the scope of our investigation and found it necessary to ask for a no-cost extension of time to enable us to complete the research in the manner we felt it deserved. In addition, we owe a particular debt to Joe for calling our attention to the need for a more through consideration of the problems of providing downtown distribution for an all-bus system. Chapters 11-13 are the result of his rather mild admonishment.

While this report could not have been completed without financial support from the Urban Mass Transportation Administration and benefited greatly from the intellectual support of members of its staff and many other individuals, its contents reflect the views of the authors who are responsible for the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation.

CONTENTS

Contents

Contents

Contents

Contents

Contents

LIST OF FIGURES

List of Figures

List of Figures

List of Figures

LIST OF TABLES

List of Tables

List of Tables

List of Tables

Chapter 1. Introduction

More than 25 years ago Meyer, Kain, and Wohl (1962, 1965) published comparative cost analyses showing that a high performance express bus system operating on congestion-free shared rights-of-ways would be the most cost-effective means of providing high-performance radial transit services between outlying residential areas and the central business districts (CBD) of large North American metropolitan areas. Other authors have proposed greater use of bus-carpool priority schemes and/or have described their implementation in a growing number of metropolitan areas both in this country and overseas.* Two high quality surveys, by Southworth and Westbrook (1985), and by an ITE (Institute of Transportation Engineers) committee (1988), for example, provide recent descriptions of the extent and utilization of operational high occupancy vehicle (HOV) facilities.

This report builds on the studies referred to above. At the same time, we have tried to go beyond previous studies and provide more of the context for the decisions to implement bus and carpool priority schemes. In doing so we have paid more attention to overall transit planning efforts and to bus operations; even the best and most comprehensive studies of HOV facilities have tended to limit themselves to descriptions of the facilities themselves, the number of persons and vehicles using them, and their impact on traffic in adjacent general purpose freeway lanes.

This report also devotes considerable attention to the problem of large scale bus operations in the downtowns of large cities, a problem which many feel is the Achilles heel of all-bus systems. In addition, it examines the post World War II experience of North American cities with exclusive busways and with new light and heavy rail systems. Finally, it compares the success and cost-effectiveness of these systems to those of bus rapid transit systems that rely on shared HOV facilities.

The fifteen chapters that follow are a rather eclectic collection of what might be thought of as case studies of the implementation of bus and carpool priority schemes in various metropolitan areas, and several chapters that present material that is more comparative in nature. These later chapters deal with common problems or attempt to synthesize or generalize from the case studies of particular metropolitan areas.

The dollar values presented in this report are in 1989 constant dollars. In the event a dollar amount is not in 1989 dollars, the current dollar year is explicitly noted in the text. Construction cost numbers are adjusted from current year values to 1989 constant dollar values using the Engineering News Record (ENR) Construction Cost Index. Operating and other costs are adjusted using the GNP Implicit Price Deflator

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* Hundreds, if not thousands, of papers and reports have been published during the past 25-30 years on bus rapid transit, bus priority, busways, high occupancy vehicle (HOV) lanes and facilities and the like. A large number of such studies are referenced in the chapters that follow. Some of the most important and influential are: Wilbur Smith and Associates (1970); Levinson, et.al. (1973); Levinson, et.al. (1975); Wilbur Smith and Associates, et.al. (1975); and NATO Committee (1976).

Chapter 2 is an example of a comparative chapter. It describes the range of bus and carpool priority measures that are currently being used in North American cities and attempts to quantify the extent of exclusive and controlled bus-carpool facilities. This turns out to be a remarkably difficult and somewhat unsatisfactory effort. No list or centralized description of bus priority schemes and operational bus-carpool facilities exists, or at least we never found one.* This is explained in part by their heterogeneity and by the fact that many of the most valuable bus priority schemes cost very little and individually have small effects. As we discuss in the chapter, however, the aggregate impacts of small scale measures can be quite large.

It is also clear that, with a few notable exceptions, highway engineers, traffic engineers, transport planners, and transit operators have not been very interested in bus-carpool priority measures. Instead, they have shown a clear preference for building additional exclusive capital intensive highways and new light and heavy rail systems. There is some signs that this is changing, but bus priority schemes, busways, and bus-HOV facilities remain something of a stepchild.**

Section II of the report, Chapters 3 and 4, describes and evaluates the largely successful efforts by transport planners and policymakers in both the New York and San Francisco-Oakland Bay Area metropolitan areas to exploit the natural channeling effect of water barriers.

As we discuss in Chapter 3, various forms of rail transit bear the brunt of carrying peak hour commuters to Manhattan's CBD. At the same time, express bus services make a major contribution, and particularly for commuters making trips from New Jersey. The bridges and tunnels connecting Manhattan to the remainder of the city and the rest of the region are the occasion for half a dozen bus and carpool priority schemes. In combination these schemes serve about 200,000 inbound transit passengers each day during the AM peak period. The inbound AM peak period contra-flow exclusive bus lane on New Jersey's I-495, connecting the New Jersey Turnpike and the Lincoln Tunnel, serves the largest numbers. Implemented in 1971, the XBL accommodated 1,600 buses and 58,000 AM inbound passengers a day in 1987. XBL buses also use an exclusive bus lane in the Lincoln Tunnel and bus-only ramps that connect the tunnel to the Port Authority Bus Terminal on the west side of midtown Manhattan.

Transport planners in the New York metropolitan area, encouraged by the success of the XBL Lincoln Tunnel scheme, have implemented a number of other significant bus priority schemes. These include the North Hudson Transitway, a 2.7 mile transitway which began operations in May 1989; a one-mile contra-flow lane on the Gowanas Expressway at the Brooklyn (southern) approach to the Brooklyn Battery Tunnel; two one-quarter mile HOV lanes on the western approach to the Holland Tunnel Toll Plaza; two inbound bus and three or more persons per vehicle (3+) carpool HOV lanes at the approach to the George Washington Bridge;

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* UMTA's Section 15 reports contain some data, which we present in Chapter 2. While of some value, these data refer to only a small part of bus-carpool priority measures and are not very detailed.

** Two positive developments that attest to the growing interest in and greater respectability of bus priority schemes are the establishment by APTA (American Public Transit Association) of a transitways working group, and three consecutive national conferences on high-occupancy vehicle lanes in transitways. APTA's Policy and Planning Committee has actually published a slick booklet describing transitways and some representative applications in North American cities (APTA, 1987). The first national conference on high-occupancy vehicle lanes and transitways was held in Orange County, California in fall 1986; subsequent conferences were held in Houston, Texas in October 1987 and in Minneapolis, Minnesota in Fall 1988. The fourth is scheduled for May 1990 in the Washington, D.C. area.

and a 2.5 mile contra-flow bus lane on the Long Island Expressway (LIE) at the Queens (east) approach to the Queens Midtown Tunnel.* These schemes as well as others that transport planners in the New York region are actively promoting are described in Chapter 3.

Like the New York metropolitan area, water barriers have had a major impact on urban development patterns, transport infrastructure, and transport policy in the San Francisco-Bay Area. In Chapter 4, we review the Bay Area's experience with bus and carpool priority schemes, particularly those that are designed to increase the person carrying capacity of the San Francisco-Oakland Bay and Golden Gate Bridges, the only direct highway connections between Oakland and San Francisco and between Marin County and San Francisco respectively.

Limited transport capacity between the East Bay and San Francisco, essentially the Bay Bridge and the Bay Area Rapid Transit (BART) subway system, and extensive bus/carpool priority schemes have combined to produce quite high peak period carpool and transit mode splits.** The first priority scheme was introduced in 1970, when California Department of Transportation (Caltrans) engineers implemented an exclusive AM inbound bus lane at the approach to the Bay Bridge toll plaza. While this simple scheme was highly effective, it prompted immediate complaints from motorists.

As in many such situations, the exclusive bus lane appeared to motorists to be grossly underutilized, even though it served more than 500 peak period buses and many more person trips than each of the general purpose traffic lanes. In December 1971, the lane was converted to a bus and 3+ carpool lane. Since then, Caltrans has made a number of other changes in an effort to encourage bus ridership and carpooling without reducing the bridge's vehicular capacity. Chapter 4 also provides a discussion of "casual" carpooling, which is quite prevalent, and a discussion of the Bay Bridge Authority's decision to exempt buses and carpools from bridge tolls.

A variety of bus and carpool priority schemes have been implemented on the Golden Gate Bridge as well, although with somewhat less success than in the case of the Bay Bridge. As we discuss in Chapter 4, transit and carpool mode splits for the Golden Gate Bridge are much less than for the Bay Bridge, even though large numbers of East Bay to San Francisco tripmakers use BART. Other Marin County to San Francisco bus and carpool priority measures include bridge toll exemptions for buses and 3+ carpools, and nine miles of discontinuous HOV lanes for buses and 2+ carpools on Highway 101, the sole route from San Francisco north to Marin County and beyond. In addition, Caltrans operated a northbound contra-flow bus lane on Highway 101 during the PM peak from September 1972 until 1983. Chapter 4 also includes a brief discussion of competing proposals for an exclusive busway and LRT in Marin County.

Section III reviews the experience with exclusive busways in Ottawa and Pittsburgh. As we discuss in Chapter 5, Ottawa-Carleton is the first, and still the only, metropolitan area in North

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* An average of 19,000 passengers and 430 buses used the Gowanas Expressway contra-flow lane and the Brooklyn Battery Tunnel to enter Manhattan during the AM peak period in 1987. The LIE contra-flow lane was used by an average of 377 buses and 14,000 passengers during the AM peak period in 1988.

** As we discuss in Chapter 4, about 76,000 AM peak period person trips per day were made from the East Bay to San Francisco in 1987. About a third of these trips were on BART and the rest used the San Francisco-Oakland Bay Bridge. Of those using the bridge, about 14 percent made their trips by bus and the rest were about equally divided between carpools and low occupancy vehicles (LOVs).

America, to consciously choose an exclusive busway system in preference to a light or heavy rail system. Transport planners and policy makers in Ottawa-Carleton reached this decision when an alternatives analysis, completed in 1978, indicated that the total cost of an LRT system would be 15 percent greater than the total cost of an exclusive busway system serving the same corridors. A 1981 update of the 1978 study, using actual construction costs for Ottawa's busways and actual construction and operating cost data for the recently completed Edmonton and Calgary LRT systems, was even more favorable to the exclusive busway.

Daily ridership on the Ottawa busways, which averages 200,000 per day, exceeds by a large amount the ridership on any new North American light rail system. As we discuss in Chapter 5, OC Transpo, Ottawa-Carleton's regional transit authority, currently operates 12.8 miles of exclusive busways with 14 stations and an additional 1.4 miles of exclusive bus lanes and five stations in the downtown area. Development of OC Transpo's exclusive busway system is continuing, and the authority expects to have completed a 19.4 mile "first stage" busway system with 24 stations by 1993. OC Transpo is also actively considering building a CBD bus tunnel, similar to the one under construction in Seattle, to further improve service and reduce congestion in the central area.

Pittsburgh is the other North American metropolitan area with exclusive busways. The region's transit authority, The Port Authority of Allegheny County (PAT) owns and operates two exclusive busways. As we discuss in Chapter 6, Pittsburgh's busways are quite short. The South Busway, for example, which opened in 1977, is only 3.8 miles long, and the East Busway, which opened in 1983, is only 6.8 miles long.

PAT also owns and operates a modern LRT system. One of the most interesting features of Chapter 6 is a brief discussion of the findings of an analysis by Allen D. Biehler, PAT's Director of Planning and Business Development, comparing PAT's exclusive busways and its new light rail transit (LRT) system. Biehler found that Pittsburgh's exclusive busways have thus far outperformed its LRT system, noting that they were less expensive to construct, have lower operating costs, and carry as many riders as the more costly LRT system.

Section IV consists of four chapters that describe the implementation of bus and carpool facilities in the Washington, D.C., Los Angeles-Orange County metropolitan regions, and Houston. As we discuss in Chapter 7, three of North America's most significant and innovative HOV facilities are located in the Washington, D.C. metropolitan area, or more accurately in Northern Virginia.

The Shirley Highway is the oldest and most intensively used of the three HOV facilities. First opened in September 1969 as an exclusive busway, and converted to a bus-carpool facility starting in December 1973, the Shirley Highway's two, reversible HOV lanes served 14,000 transit users and 33,000 persons overall (buses plus carpools) during the AM peak period (6-9 AM) in May 1988.

Chapter 7 also contains a discussion of the planning for and implementation of the I-66 extension, a 10 mile four lane parkway (two lanes in each direction) that runs between the Capital Beltway (I-495) and the Roosevelt Bridge over the Potomac into the District of Columbia. In 1982, the I-66 HOV extension was opened as the nation's <u>first</u>, and still only, peak period, peak direction <u>bus and carpool highway</u>. At the present time only buses and 3+ carpools are

allowed to use the road inbound (toward the District) during 7-9 AM and outbound during 4-6 PM. There are no occupancy restrictions during the rest of the day or in the off-peak direction.

The third HOV facility, the I-95 Median Diamond Lanes, was implemented by the Virginia Department of Transportation in December 1985 as an interim, low cost extension of the Shirley Highway HOV lanes. While neither the I-95 diamond lanes or the I-66 HOV Parkway carry as many persons in carpools as the Shirley Highway, they make important contributions to reducing peak period congestion in the Washington, D.C. region.*

Chapter 8 contains a description of Los Angeles' El Monte Busway and its operations from the time it opened as an exclusive busway in 1973 to the present, when it functions as a bus-3+ carpool HOV facility. As we discuss in Chapter 8, bus ridership on the El Monte Busway grew rapidly from the time that it was first opened until June 1974, when 3+ carpools were allowed to begin using the facility. Bus ridership declined after carpools were allowed to begin using the busway, and has tended to fluctuate, showing little, if any, trend, since then. Opening the busway to carpools, however, allowed total person trips (transit plus carpools) on both the busway and on the entire freeway (busway plus general traffic lanes) to continue to grow rapidly for another six years. Since 1980, the growth in total person trips has been quite modest for both the busway and the entire freeway.

Chapter 9 describes efforts to implement other HOV facilities in Los Angeles and Orange County. The backlash from the first of these efforts, the Santa Monica Diamond Lane project, was so extreme that it was more than a decade before the region's transport planners and policymakers were willing to try to implement another HOV facility. In addition to describing the results of the Santa Monica Freeway Diamond Lane project and examining the reasons for its failing, this chapter also reviews the successful implementation of "commuter" lanes on the Artesia Freeway (Rte. 91) and on the Costa Mesa Freeway in Orange County (Rte. 55). Finally, we describe Orange County's plans for an extensive system of transitways and commuter lanes.

As Chapter 10 makes clear, the origins of Houston's remarkable transitway system are found in its highly successful North Freeway contra-flow lane. A proposal for the North CFL, as it came to be called, was made in 1974 by the Texas State Highways and Transportation Department, as the SDHPT was then known, four years before METRO was created. The North CFL was opened to buses and authorized vanpools on August 28, 1979, shortly before METRO began operations.

METRO's "approved" transitway plan includes 95.5 miles of transitway in six radial freeway corridors. One reason the METRO board voted not to build the rail system connector was that the Rail Research Study, METRO's reevaluation of the rail system connector plan, indicated that implementing the rail system connector would very likely have an adverse effect on the performance of Houston's rapidly developing transitway system and reduce transit ridership.

Section V deals with downtown distribution. Chapter 11 examines the nature and extent of the downtown distribution problem and in particular considers the contribution buses make to

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* In combination, the three facilities served nearly 19,000 bus passengers and nearly 59,000 total person trips during the AM peak period in May 1988.

serving the downtowns of large North American cities. The chapter clearly shows that the notion that buses are responsible for the congested conditions that exist in the central business districts of most large cities is unfounded. Buses carry a large fraction of peak hour trips to and from the CBDs of large cities, but use only a small fraction of available street space. The analyses presented in Chapter 11 also identifies changes in bus operations that would greatly reduce the amounts of central area street space required for bus operations.

Chapter 12 reviews low and moderate capital cost approaches to central area distribution, and particular transit malls, which have been proven a cost-effective way of improving downtown distribution, and, perhaps even more importantly, of improving the environment of central areas for both transit users and pedestrians. The chapter first describes the bus malls that have been implemented in seven cities since 1967.* We were able to visit two of these cities, Portland and Denver, as part of the study and our assessment of bus malls emphasizes their experience.

Portland may have the most successful transit mall currently operating in North America. It is the only mall that appears to provide clear-cut travel time savings for buses. The success of Portland's transit mall is due in no small part to the decision to allocate most of two downtown streets to transit use. This arrangement greatly reduces the "presence" of buses in downtown by distributing them over two streets instead of one; moreover, it permits a generous allocation of space for passenger loading areas and other amenities and two exclusive bus lanes, so that buses do not have to stop at every stop.

As we discuss in Chapter 12, we also visited Denver to view its transit mall. Denver's approach was very different from Portland's. In contrast to Portland, which moved all of its CBD bus routes to the mall, which serves as the downtown distributor for the bus system, Denver operates only specially designed electric buses on its 16th Street Transit Mall. Denver's mall connects express/regional bus terminals located at either end of the mall. Residents using express buses to reach downtown must either transfer to the mall shuttle or walk to their ultimate destinations. When the mall was being planned, the region's transport planners were concerned about the effect of these forced transfers on transit ridership. While there has been no formal analysis, transit authority analysts and managers take the position that the impact has been negligible and is more than offset by other benefits. According to the transit authority's analysts, these benefits include removing large numbers of buses from the downtown streets. At the same time, the mall does not serve the large number of local buses that enter the downtown; these local buses had to be moved to other CBD streets when the mall was implemented.

As we discuss in Chapter 12, we were somewhat disappointed with the Denver Mall. The visual and physical environment of the Denver Mall is simply less pleasing than those of the Portland Mall. As we discuss in Chapter 12, we believe design error is the explanation. At the same time, we acknowledge that, the differences may also be due to a considerable extent to the fact that the Portland Mall is eight years older than the Denver Mall, and the trees, which have so much to do with creating a pleasant environment on the Portland Mall, have had more time to grow. Trees also grow more rapidly in Portland than in Denver.

* The cities and the date their malls were implemented are: Minneapolis (1967), Vancouver (1973), Chicago (1975), Philadelphia (1975), Portland (1978), Denver (1982), and Honolulu (1988).

Chapter 12 also discusses successful efforts by San Francisco planners to improve bus operations on Market Street. After Market Street merchants and the mayor vetoed a Market Street transit mall, the city's planners devised and were able to implement a scheme that by allocating more space to buses. By implementing appropriate traffic engineering measures, they dramatically improved transit operations and passenger comfort and safety, and, in essence, created a de facto transit mall.

The final section of Chapter 12 describes the implementation of segregated busways in the arterial streets of several Brazilian cities. These segregated busways, which overcome many of the problems associated with bus-lanes, accommodate very high passenger volumes and achieve door to door travel speeds that, some Brazilian transport planners argue, are equal to or better than those provided by costly heavy rail systems.

Chapter 13 reviews more capital intensive approaches to improving the downtown distribution of all bus systems. It begins with a discussion of bus tunnels. As this discussion points out, bus tunnels are hardly a new idea. Harvard Square has had a bus tunnel since 1912, and Meyer, Kain, and Wohl (1965) included CBD bus tunnels in their analysis of the comparative cost of alternative high performance transit modes.

More recently, Seattle has completed a CBD bus tunnel, and Ottawa is actively considering building a bus tunnel to replace the downtown bus lanes which currently act as a low capital cost downtown distribution system for its innovative exclusive busway system. Chapter 13 contains a fairly detailed description of Seattle's CBD bus tunnel and the alternatives analysis that were used to justify its construction. The planning for Ottawa's bus tunnel and the proposed design are described in Chapter 5.

The final section of Chapter 13 discusses Detroit's and Miami's experience with downtown people movers, which have long been suggested as a cost-effective means of providing downtown distribution for radially oriented bus transit systems and for improving access within downtowns. While the people mover systems have only been operating in Detroit and Miami since 1986, their performance thus far has been disappointing. Ridership on the Miami people mover has been only 26 percent as large as forecast, and ridership on the Miami system has been only 16 percent of the forecast levels.

Section VI consists of three chapters that compare the cost-effectiveness of exclusive busways and bus-HOV facilities to light and heavy rail systems and discuss how best to achieve and maintain the reliable 55 mph speeds needed for high performance rapid transit.

Chapter 14 compares exclusive busways to light rail transit. As this discussion points out, what has come to be known as light rail or LRT bears a close resemblance to the electric street railways that briefly dominated the nation's urban transportation scene after their invention at the turn of the century. Chapter 14 thus examines the reasons for the rise and fall of electric street railways before discussing the recent light rail revival.

The examination of the nation's experience with electric street railways is followed by a fairly extensive review of the scholarly evidence relating to the cost of alternative urban transport modes. As we reveal in Chapter 14, the comparative cost analyses and claims about the cost-effectiveness and operational feasibility of high-performance and high-capacity bus rapid transit

systems made by Meyer, Kain, and Wohl (1962, 1965) a quarter of a century ago have stood the test of time. Subsequent studies suggest their findings about the superiority of bus rapid transit in medium and low density cities were valid and, if anything, conservative.

In spite of the near unanimity among academic transport planners and economists about the superiority of bus rapid transit, alternatives analyses for particular urban areas, with few exceptions, tend to find that light and heavy rail have <u>lower</u> costs than exclusive busways. Chapter 14 provides a fairly extensive discussion of the reasons for this seeming paradox. Examining the experience in Houston and Atlanta, we find that transport analysts in these areas reached the conclusion that rail would be cheaper than bus rapid transit because that is what they set out to find.

The chapter also reviews the actual cost and operations experience in Ottawa and Pittsburgh, the two North American cities that have implemented exclusive busways. Their experience strongly supports the findings of "objective," academic studies about the superiority of bus rapid transit. Further evidence is provided by Pickrell's (1989) careful study of the projected and actual performance of new federally funded rail systems. While Pickrell does not compare rail and bus systems, he does demonstrate that the costs of new light and heavy rail systems have been consistently underestimated and that their ridership has been consistently overestimated.

The final section of Chapter 14 describes the guided busway system recently implemented in Adelaide, Australia. Advocates of the guided bus system contend that its retains all of the technological advantages of bus rapid transit, especially its ability to operate on city streets and roads, and at the same time provides most, if not all, of the advantages that have been claimed for modern LRT systems.

Chapter 15 is an examination of the cost-effectiveness of shared bus-HOV facilities, relative to exclusive busways and light and heavy rail lines. Exclusive busways and light and heavy rail lines typically require only a fraction of their capacity to serve peak hour users. This is true of bus transit systems as well, but they have the great advantage of being able to share the capital costs of the roadways they use with other users. Data presented in Chapter 15 reveal that buses using operational bus-HOV facilities require less than 20 percent of the capacity of a single HOV lane. Since the peak hour volumes carried on new LRT lines are no larger, the same result presumably holds for them as well.

Chapter 15 presents comparisons of capital costs per transit trip for bus-HOV facilities, for exclusive busways, and for new, federally funded light and heavy rail systems. One of the findings of this analysis is that the capital costs per transit trip of light and heavy rail systems are quite similar. At $39,038 per transit round trip, new LRT systems cost 97 percent as much per rider as new heavy rail systems. We were somewhat surprised by this result given the claims by LRT advocates. Analyses presented in Chapter 15 make it clear that LRT may cost less per city than heavy rail, but LRT capital costs per rider served are not appreciably different from those for heavy rail. By comparison, at $3,995 and $7,470 per round trip, the capital costs of the Ottawa and Pittsburgh LRT systems are only 10 percent and 19 percent as large as the average per round trip capital costs of the four new, federally financed light rail systems studied by Pickrell (1989).

If only transit trips are considered, the per trip capital costs of the El Monte Busway and Shirley Highway, the two oldest and most heavily used bus-HOV facilities, are considerably higher than the comparable figures for the Ottawa and Pittsburgh exclusive busways, although these costs are still only 23 percent and 42 percent as large as the comparable figures for modern LRT systems. As Chapter 15 reveals, however, at $4,999 and $3,931 per total round trip (transit trips plus vanpools and 3+ carpools) the total per trip capital costs of these bus-HOV facilities are less than those for the Pittsburgh exclusive busways and slightly less than (El Monte Busway) and about 30 percent more (Shirley Highway HOV lanes) than those for the Ottawa Exclusive Busways.

Chapter 15 also contains an evaluation of what are variously referred to as diamond or commuter lanes. As this analysis make clear, the "incremental" capital costs of these facilities are quite low. Incremental capital costs for the three diamond - commuter lane facilities discussed in Chapter 15 range from a high of $413 per total round trip for the I-95 Diamond Lane in Northern Virginia to a low of $23 per total round trip for the Route 55 commuter lane in Southern California. The incremental capital costs of the I-95 Diamond Lanes per person trip are one percent of the capital costs per person trip of the four new light rail systems studied by Pickrell; the same figure for the lower cost Route 55 commuter lane is 0.04 percent. The key word here is "incremental." These facilities are principally carpool lanes, and the larger part, by far, of the costs of providing them are the forgone benefits from not using them as general purpose traffic lanes. Implementing these HOV lanes entailed little more than the costs of re-striping the freeways, signing, and in at least one case the construction of an emergency shoulder.

The final chapter is concerned principally with an examination of how best to achieve the congestion free shared roadways that are needed for bus rapid transit systems, and of the effect of the time savings provided by various priority measures on transit ridership and carpooling.

Chapter 16 begins with a discussion of "Making the Freeway Fliers Fly." As we discuss in Chapter 16, Meyer, Kain, and Wohl (1962, 1965) used the term "Freeway Fliers" to describe express buses operating on shared congestion free freeways or other high performance grade-separated mixed traffic roadways.* As we also observe in Chapter 16, while the analyses published in the Urban Transportation Problem unambiguously demonstrated the superiority of freeways fliers in terms of both cost and performance, Meyer, Kain, and Wohl (1965) were rather vague about how transport planners and policy makers should achieve the required sharing of general purpose facilities and low congestion levels.

In an effort to answer this question, Chapter 16 examines the relative merits of exclusive freeway bus lanes, the use of ramp meters to achieve and maintain congestion-free roadways, and what has emerged as the most common approach, separate bus-carpool lanes. Illustrative calculations presented in Chapter 16 suggest that a mixed strategy, which operates the freeway main lanes at 30 mph, the speed that in most situations will maximize vehicular flow, and separate bus-carpool lanes, which are operated at 50-55 mph speed may be the best approach to maximizing total net benefits.

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* As we point out in subsequent chapters, Freeway Fliers was the name Los Angeles' transit system gave to its highly successful freeway express bus services. Meyer, Kain, and Wohl (1965) borrowed the term to describe their proposed express bus services, which were assumed to operate on shared, congestion controlled, grade-separated facilities.

The discussion of alternative bus priority strategies in Chapter 16 clearly indicates that the success of bus priority schemes depends critically on the response of tripmakers to the time savings provided by bus-carpool lanes and other bus-carpool priority schemes. Thus, the final section of Chapter 16 reviews what is know about the determinants of mode choice. It is clear from this review that a considerable amount is known about transit demand and the effect of improvement in transit speeds on transit ridership. Much less is known about how the time savings from bus-carpool priority schemes affect carpool use; yet in many situations the answer to this question is crucial.

A good case can be made for reading this report from back to front, i.e. for reading the more general and summary material in Chapters 14-16 before proceeding to the more specific case materials describing particular metropolitan areas or other specific subject matter. Indeed some readers may simply want to limit their careful reading to Chapters 14 and 15, which evaluate and provide cost-effectiveness comparisons of light and heavy rail systems, exclusive busways, and bus rapid transit systems that rely primarily on shared, congestion controlled high-performance highways. Other readers may be principally interested in the chapters, i.e. case studies, that describe the experience of particular metropolitan areas, and still others may be interested in particular topics, such as the extensive discussion of downtown distribution presented in Section VI (Chapters 11 - 13).

The report is written in such a way that all of the options outlined above are possible. With minor exceptions, each of the 16 chapters is self-contained. These observations about the report's organization are not meant to discourage readers who are accustomed, and prefer, to read books and reports from front to back. For these readers, the next chapter provides something of an overview. Specifically, it contains a discussion of the range and extent of bus priority schemes currently operating in North American cities.

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Chapter 2. Priority Measures to Increase Transit Use and Carpooling

Introduction

Chapters 3 through 10 of this report describe measures implemented in a number of metropolitan areas in North America since the end of World War II to increase the productivity of urban streets and highways. While this study emphasizes measures that increase bus transit speed, performance, and ridership, many of the policies considered also encourage greater use of vanpools and carpools. As we discuss in Chapter 15, sharing expensive, high-performance facilities with carpools and vanpools provides substantial direct benefits to the members of these carpools and dramatically increases the cost-effectiveness of high-performance bus systems that use shared facilities.

While efforts to improve the productivity and performance of urban streets and highways have become more commonplace, it is very difficult to quantify this growth or even to provide anything approaching a complete enumeration. One reason is that many of the most effective measures are small and inexpensive improvements that, when they work properly, are hardly noticed. Taken one at a time, these small measures provide only very small increases in transit speeds and reliability, but, in combination, they may result in large and significant improvements in transit operations. Developing and maintaining a successful high-performance transit system, whether an all-bus system or a bus-rail system, depends critically on attention to detail and on improvements at the margin. It is essential that the hundreds, if not thousands, of decisions about bus operations, traffic engineering, and highway design affecting transit speeds and performance that are made every year, are made in ways that improve, rather than worsen, system performance.

The measures discussed in this report include operating practices that improve bus transit speeds and reliability, such as increased use of express and limited stop services, changes in bus networks to provide better coverage, and more direct services; a variety of roadway improvements; traffic engineering schemes; and Transport System Management (TSM) policies. Some of these measures may also be used to increase carpool speeds, reliability, and usage. A partial list of these bus/carpool priority measures includes:

- Exclusive streets and roads for buses and transit malls;
- Preferential tolls, bypasses, and exclusive lanes at bridges and tunnels;
- Concurrent-flow exclusive bus-lanes or bus-HOV lanes on arterial streets and on expressways;
- Contra-flow exclusive bus-lanes on arterials and on expressways;
- Exclusive expressway ramps or bypasses at metered on-ramps for buses, carpools, and vanpools;

- Preferential parking charges and locations for carpools and vanpools;
- Free and/or subsidized park and ride lots;
- Signal preemption and other traffic engineering measures that favor buses.

Some of these measures directly increase transit speeds, others lower the non-time cost of using transit, and some do both.

Exclusive and Controlled Transit Rights-of-Way

The principal focus of this report is on the development and use of exclusive busways, transitways, Bus-HOV (high occupancy vehicle) facilities on limited access highways, and on problems related to bus use of the downtown streets. This emphasis, however, should not be allowed to obscure the fundamental fact that, even in those few areas with extensive rail systems, bus routes that operate in mixed traffic on general purpose urban streets and arterials account for the bulk of transit route and passenger miles.

Statistics on "directional route miles" collected by the Urban Mass Transit Administration as part of its Section 15 reporting requirements show the crucial role of surface street operations. "Directional route miles" are defined as:

> ... the mileage service operates in each direction over routes which public transportation vehicles travel while in revenue service. Directional route miles are a measure of the facility or roadway, not the service carried on the facility, i.e. number of routes or vehicle revenue miles. They are determined by direction of service, but not by the number of traffic lanes or rail tracks existing in a given right-of-way. If vehicles travel in only one direction, each mile is counted once. If vehicles travel in both directions, each mile is counted twice. A mile of single track over which streetcars operate in both directions represents two directional route miles. And a mile of exclusive busway on which a transit company operates six different routes in only a single direction represents one directional mile, regardless of the number of lanes (Technology Applications, Inc., 1987, p. 3-7).

Information, supplied by individual transit operators, on directional route miles of transit right-of-way by mode in 1985 are summarized in Table 2-1. The information is shown separately for areas with rail transit (heavy rail, commuter rail, LRT, or streetcars) and for areas that have no rail transit service.* As these data indicate, over 96 percent of all directional route miles of public transit are on general purpose urban highways and streets. Even in areas with extensive rail systems, road based modes accounted for nearly 86 percent of all transit route miles in 1986.

Of the rail based modes, commuter rail supplied the most route miles, 2.5 percent of all directional route miles in 1986. Directional route miles for heavy rail systems comprised only 0.9

* Table 2-1 omits 210 directional route miles of ferry services.

Table 2–1. Summary Statistics on Directional Route Miles for Rail and Non–Rail Areas by Mode, 1986

	Directional Route Miles of Highway				Rail Systems			
Type of Area and Mode	Exclu– sive	Con– trolled	Exclusive plus Controlled	Mixed ROW	Direc. Route Miles	Miles of Track	No. of Cross– ings	No. of Sta– tions
Areas With Rail								
Automated Guideway Transit	0	0	0	0	4	4	0	9
Cable Car	0	0	0	0	9	9	61	0
Commuter Rail	0	0	0	0	3,183	3,931	1,387	805
Inclined Plane	0	0	0	0	0	0	0	2
Motor Bus	53	126	179	29,099	0	0	0	0
Rapid Rail	0	0	0	0	1,312	1,695	28	925
Streetcar/LRT	0	0	0	0	401	442	2,192	190
Trolley Bus	22	152	174	0	0	0	0	0
Total Rail Cities	75	278	353	29,099	4,909	6,081	3,668	1,931
Areas Without Rail								
Inclined Plane	0	0	0	0	2	1	0	2
Motor Bus	93	246	339	110,770	0	0	0	0
Trolley Bus	232	0	232	0	0	0	0	0
Total Non–Rail Cities	325	246	571	110,770	2	1	0	2
Total All Cities	400	524	924	139,869	4,911	6,082	3,668	1,933

Source: UMTA, 1986 Section 15, Table 3.12.1, TSC–10/13/88.

percent of all transit route miles in 1986, while street car and LRT (Light Rail Transit) services were only 0.03 percent of total directional route miles.

Motor bus operators in U.S. urban areas reported 146 miles (directional) of exclusive right-of-way, and 372 miles of controlled right-of-way for a total of 523 miles of either exclusive or controlled right-of-way (Table 2-1). Of the 146 miles of exclusive right-of-way, 53 miles were located in areas with at least some rail service and 93 miles were located in areas with no rail service.* The distinction between exclusive and controlled right-of-way, somewhat surprisingly, has to do with whether the restrictions apply to the entire day or only part. Exclusive right-of-way may be made available to carpools and vanpools as well as buses.

The data in Table 2-1 also reveal that trolley buses use nearly as many route miles of exclusive and controlled roadway as motor buses, even though they account for only a miniscule share of total bus route miles. These data also seem to suggest that all trolley buses operations take place only on exclusive or controlled right-of-way. A visit to Boston, Seattle, or

* Transit operators have a strong incentive to report directional miles of exclusive and controlled highway right-of-way. The total route miles enter into the formula used to apportion Section 9 subsidies under the block grant program created by the Surface Transportation Assistance Act (STA Act) of 1982. Nonetheless, the inclusion of the data in the formula is of relatively recent origin and some operators may have failed to report them (Technology Applications, Inc., 1987, p. 1-7).

other cities with trolley bus operations suggests otherwise. Trolley bus route miles on general purpose streets and arterials must either be included as part of motor bus operations or eligibility criteria for qualifying trolley bus route miles for Section 9 subsidies must be quite minimal.

Table 2-2 gives route miles of exclusive, controlled, and mixed right-of-way by operator for the 40 motorbus operators that reported one or more miles of exclusive or controlled routes in 1986.* These data reveal that ten transit systems claimed more than 20 miles of exclusive or controlled highway right-of-way and eight more claimed more than 10 miles, but less than 20. The systems claiming more than 20 miles were: Washington, D.C., Seattle, Santa Barbara, Santa Clara, Toledo, Richland-Ben Franklin (Washington), New York, Pittsburgh, Los Angeles and Houston. The systems reporting more than 10, but less than 20 miles were the Lane Transit District in Oregon, St. Louis, Miami, Denver, Dallas, San Juan, San Francisco-Marin County, and Minneapolis-St. Paul

Exclusive Busways

The Port Authority of Allegheny County (PAT), Pittsburgh's principal transit provider, reported 27 miles of exclusive right-of-way in 1986. Of this total, two exclusive busways, the East and the South Busway, completed in 1983 and 1977 respectively, accounted for 20.6 miles. These two busways, which are discussed in Chapter 6, are the only grade-separated exclusive busways currently operating in the United States. Buses using these two facilities carry approximately 47,000 transit passengers a day; about 29,000 per day use the East Busway and about 18,000 use the much shorter South Busway (APTA, 1987. p. 15).

Only one other transit operator in North America has built exclusive busways. Ottawa, Canada is the first, and still the only, metropolitan area in North America to eschew light and heavy rail in favor of a high performance bus system based on an exclusive busway system. The first phase of Ottawa's system, which is described in Chapter 5, consists of 19.6 miles of two-lane roadway (39.2 directional route miles) and 26 stations and is scheduled to be completed by 1990; a further 16.9 miles of transitway will be built during the 1990's. Two segments of the system totaling 12.5 miles are already operating and are carrying about 210,000 passengers a day, including about 9,000 peak hour, peak direction passengers on each of the two segments (APTA, 1987. p. 15). Since Ottawa is a Canadian city, its miles of exclusive right-of-way are not included in Tables 2-1 and 2-2.

Freeway Bus-HOV Facilities

Quite a few U.S. transit authorities have implemented suburban-downtown, express bus services on shared bus-HOV facilities. These HOV lanes, which are normally developed by and remain under the jurisdiction of state highway departments, differ from the exclusive busways in Pittsburgh and Ottawa in that they are typically located in freeway rights-of-way, and are available for the use of varying combinations of vanpools and carpools as well as buses. As we

* Several operators report less than one mile of exclusive or controlled right-of-way transit. These are not included in Table 2-2.

Table 2–2. Directional Route Miles of Exclusive, Controlled and Mixed Right–of–Way by Transit System, 1986

State	Transit System	Directional Route Miles of ROW Exclusive	Controlled	E + C	Percent E or C	Mixed ROW
DC	Washington Metro Area TA	0	44	44	1.6	2,731
WA	Seattle METRO	30	10	40	2.1	1,940
CA	Santa Barbara MTD	0	40	40	20.1	198
CA	Santa Clara County TD	0	36	36	2.8	1,289
OH	Toledo RTA	0	35	35	4.4	795
WA	Richland–Ben Franklin	0	34	34	14.8	230
NY	New York CTA	1	30	31	1.8	1,714
PA	Pittsburgh – PAT	27	0	27	1.1	2,404
CA	Los Angeles – SCRTD	2	22	24	0.5	4,915
TX	Houston – METRO	19	4	23	1.2	1,910
OR	Lane Transit District	0	18	18	3.5	518
MO	St. Louis – Bi–State	8	9	17	0.8	2,139
FL	Miami–Dade City TA	0	15	15	1.2	1,256
CO	Denver – RTD	2	9	11	0.5	2,267
TX	Dallas Transit System	0	11	11	0.8	1,500
PR	San Juan–Metro Bus Auth	11	0	11	3.2	352
CA	San Fran–Golden Gate TD	0	11	11	2.3	487
MN	Minneapolis MTC	10	0	10	0.4	2,517
MA	Boston – MBTA	8	1	9	0.6	1,413
CA	San Francisco Muni	0	9	9	1.9	443
IL	Chicago – CTA	8	0	8	0.6	1,401
NJ	Newark–NJT Corp.	0	7	7	0.2	3,086
HI	Honolulu DOT Srv	0	6	6	0.8	817
WI	Madison METRO	0	6	6	1.8	355
PA	Philadelphia – SEPTA	2	2	4	0.2	2,378
CA	San Diego TS	4	0	4	0.5	945
GA	Atlanta – MARTA	4	0	4	0.2	1,886
NY	New York – Jamaica Bus	0	3	3	7.0	43
IN	Indianapolis PTC	3	0	3	0.3	883
NJ	Bergenfield–Rockland TC	0	3	3	0.7	393
LA	New Orleans – RTA	2	0	2	0.4	522
CA	Long Beach PTC	0	1	1	0.3	407
OR	Portland Tri–County MTD	0	1	1	0.1	1,353
CA	Alameda–Contra Costa TD	0	1	1	0.0	2,345
PA	Harrisburg – CAT	1	1	2	0.8	120
NY	New York Bus Tours, Inc.	0	1	1	0.8	119
OH	Kent Campus Bus Service	1	0	1	1.2	58
IA	Des Moines MTA	0	1	1	0.2	300
OH	Cincinnati – SORTA	1	0	1	0.0	1,235
MO	Kansas City Area TA	0	1	1	0.1	835
Total		144	372	516	––	50,499

Source: UMTA, 1986 Section 15, Table 3.12.1, TSC–10/13/88.

discuss in Chapter 17, permitting vanpool and carpool use of these facilities substantially increases the number of persons served and greatly reduces the effective capital cost per user of these facilities.

Frank Southworth and Fred Westbrook (1985, p. E-1) in a recent nationwide study of HOV lanes identified "17 'mainline' HOV lanes projects in operation around the country that allow carpools and/or vanpools as well as buses exclusive access." In addition they refer to four "mixed rideshare/bus HOV lane projects" that provide toll booth bypasses and toll exemption. All four schemes, New Jersey's/New York's Holland Tunnel, New York's Lincoln Tunnel, New York's Gowanus Expressway, and the San Francisco-Oakland Bay Bridge Plaza are discussed in Chapters 3 and 4.

Table 2-3 provides brief descriptions of 29 freeway bus/HOV facilities, seven exclusive HOV facilities, 15 concurrent flow freeway HOV lanes, and seven contra-flow freeway HOV lanes. These include the 13 freeway bus-HOV projects identified by Southworth and Westbrook, those listed in a recent ITE (Institute of Transportation Engineers) Committee report (1988), and a small number of additional facilities that were overlooked by the authors of either survey. The facilities are grouped using the categories and definitions suggested by the ITE Committee report:

> Exclusive HOV Facilities, Separate Right of Way. A roadway or lane(s) developed in a separate right-of-way and designated for the exclusive use of high-occupancy vehicles.
>
> Exclusive HOV Facility, Freeway Right-of-Way. Roadways or lanes built within the freeway right-of-way that are physically separated from other freeway lanes and are designated for the exclusive use of high-occupancy vehicles during at least portions of the day.
>
> Concurrent Flow Lane. A freeway lane in the peak-direction of travel (commonly the inside lane), not physically separated from the other general traffic lanes, and designated for exclusive use by high-occupancy vehicles (usually buses, vanpools, and carpools) during some portion of the day.
>
> Contra-flow Lane. A freeway lane (commonly the inside lane in the off-peak direction of travel), designated for exclusive use by high-occupancy vehicles (usually buses, vanpools, and carpools) during at least portions of the day. The lane is typically separated from the off-peak direction travel lanes by removable plastic posts or pylons (ITE, 1988, p. 1).

Table 2-3 includes all of the freeway bus-HOV facilities we were able to identify either by direct contact with the relevant agencies or from secondary sources. In spite of their diligence, Southworth and Westbrook and the ITE Committee overlooked a few existing and proposed bus-HOV facilities. For example, they both missed the Boulder Freeway concurrent flow facility, a highly successful one-way, median concurrent flow lane on the Boulder Freeway between Boulder and Denver operated by the Denver Rapid Transit District (RTD). In addition, the Denver RTD is currently completing an Environmental Impact Study (EIS) for a physically separated, median busway on North I-25. As currently envisioned, Denver's I-25 North Busway would be a 12.6 mile two-lane reversible, barrier-separated facility in a 40 foot envelope (two 12 foot lanes

Table 2–3. Characteristics of Operational HOV Facilities

Facility and Type	Location	Opening Date	Route Length	HOV Modes	Number of Lanes GT	Number of Lanes HOV	Peak Period Total Persons	Hours
Exclusive Facilities								
Shirley	Virginia	1973	12.0	Bus, 4+CP	4	2	16,740	6–9AM 4–7PM
I–10	El Monte	1977	11.0	Bus, 3+CP	4–5	1	15,800	Continuous
I–66	Virginia	1982	10.0	Bus, 3+CP	0	2	5,353	7–9AM 4–6PM
North	Houston	1984	9.1	Bus, VP	3–4	1	7,800	4AM–1PM/
Katy	Houston	1984	11.5	Bus, 2+CP	3–4	1	8,386	PM–10PM
Gulf	Houston	1986	4.0	Bus, 2+CP	3–4	1	2,685	same
Northwest	Houston	1988	9.0	Bus, 2+CP	3–4	1	2,642	same
Concurrent Flow								
Moanalua Fwy	Honolulu	NA	2.7i/1.4o	Bus, 3+CP	NA	1	NA	24 Hrs.
Rt.163	San Diego	NA	0.9	Bus	NA	1	NA	3–6 PM
I–280	San Francisco	1965	1.6	Bus, 3+CP	3	1	970	Continuous
Bay Bridge	San Francisco	1970	0.9	Bus, 3+CP	NA	3	NA	6–9AM 3–6PM
US 101	Marin County	1976	3.7	Bus, 3+CP	NA	1	7,080	4–6.30 PM
I–93	Boston	1974	1.4	Bus, 3+CP	2	1	5,390	6.30–9.30 AM
Banfield	Portland	1975	1.7w/3.3e	Bus, 3+CP	2	1	1,497	6.30–9.30 AM
N.C Xpress.	Dallas	1975	12.0	Bus	NA	1	NA	AM/PM Peak
I–95	Miami	1976	7.5	Bus, CP	4	1	3,705	7–9AM 4–6PM
I–45N	Houston	1981	NA	Bus, VP	NA	NA	NA	3.45–6.30PM
Rt. 520	Seattle	1977	2.0w	Bus, 3+CP	2	1		
I–5	Seattle	1983	6.9s/5.0n	Bus, 3+CP	3–4	1	NA	Continuous
Rt.237	Santa Clara	1984	4.6e/4.4w	Bus, CP	2	1	4,540	5–9AM 3–7PM
Rt.55	Orange County	1985	11.0	Bus, 2+CP	NA	1	NA	Continuous
Boulder Fwy	Denver	1987	1.9	Bus	NA	1	NA	AM Peak
Contraflow								
I–45N	Houston	NA	NA	Bus,VP	NA	NA	7,800	NA
Long I.Xpr	New York, NY	NA	2.0	Bus	6	1	NA	7–9 AM
US 101	S.F	NA	NA	NA	NA	NA	NA	NA
I–495	NY–NJ	1970	2.5	Bus	NA	1	NA	6–10 AM
SE Xway	Boston	1971	8.4	Bus	3	NA	NA	6:30–9:30 AM
US 101	Marin Co.	1976	3.7	Bus, 3+CP	3	1	7,080	6–9AM 4–7PM
Kalanianole	Honolulu	1978	2.2	Bus, 4+CP	NA	1	NA	5–8.30 AM

Notes: CP – carpools; VP – vanpools; o – outbound; i – inbound; w – westbound; e – eastbound; s – southbound; n – northbound.
Observation dates for peak period person counts varies by facility.

Source: ITE (1980); Southworth and Westbrook (1983); Levison, et al. (1973); various sources.

with 4 foot and 11 foot shoulders. Current plans call for Denver's I-25 North Busway to be used by buses and 3+ carpools. RTD planners hope to implement the first phase, which will be more than five miles in length, by the end of 1991.

Southworth and Westbrook (1985, p. E-2) provide the following summary of their analysis of the extent of existing and planned HOV lane projects.

> The 1980's have seen a good deal of HOV lane activity: 6 HOV lane projects have been implemented since November of 1982, and since 1983 3 HOV lane projects have been abandoned, while 2 others have recently been suspended to allow highway reconstruction. At the time of writing there were approximately 118 miles of HOV lane in operation around the country, and approximately another 135 miles awaiting highway construction-reconstruction and currently scheduled to begin operation by 1989.

The ITE "Committee on the Effectiveness of High-Occupancy Vehicle Facilities" also refers to the growing acceptance of HOV projects but also comments on the troublesome problem of continuing public doubts about the merits of HOV facilities. Skepticism remains in spite of clear evidence that, in most instances, these projects significantly increase the capacity and performance of urban highway systems:

> Priority facilities for high-occupancy vehicles (HOV) are steadily gaining acceptance throughout North America. A consensus appears to exist that, in the proper environment, priority HOV lanes can be an effective means of increasing the person movement capacity of a corridor.
>
> Acceptance or agreement as to what constitutes a "successful" HOV facility is also unresolved. Many examples exist of HOV lanes that are carrying more person trips than adjacent freeway lanes. But public perception of success apparently does not fully acknowledge or understand the relationship of person trips on HOVs to person trips on normal freeways or arterials. Public perception and success is focused more on whether or not the facility appears to be fully utilized, i.e., vehicular flow rate (ITE, 1988, pp. 28-29).

Toll Plaza Bypasses and Preferential Toll Charges

Charging buses, vanpools, and carpools lower rates on toll facilities and/or permitting them to bypass the queues that tend to develop at toll plazas for toll roads, bridge crossings, and tunnels during peak periods is a simple and inexpensive way of encouraging greater transit and carpool use without making major capital investments. While these techniques have been effectively used in a number of metropolitan areas, much more could be done. For instance, inexpensive physical improvements (particularly the construction of inexpensive bus-only slip ramps at strategic locations) might produce significant increases in transit ridership on urban tollroads such as the Massachusetts Turnpike extension (Boston) and the North Dallas Tollroad.*

* Tollroads, because they charge users each time they use the facility provide excellent opportunities to increase transit and carpool use and to maximize user benefits by varying the tolls by time and day and vehicle type. Unfortunately, few exploit these opportunities. It is reasonably clear, for example, that many urban tollroad operators allow more congestion than is desirable because they believe it maximizes revenue or because of fears about opposition to efforts to increase tolls. User benefits in many situations would be increased by revenue neutral changes in tolls that would charge higher tolls during peak hours than off-peak and that gave progressively larger discounts to multiple occupant vehicles (where the size of the discount increased as the number of occupants increased).

Thomas A. Batz, in a 1986 report to UMTA, identifies seven examples where toll authorities have provided preferential charges and/or bypasses for carpools (pp. E-5 to E-9). Three of the examples, the Hudson River, San Francisco-Oakland Bay Bridge, and Golden Gate Bridge crossings are discussed in detail in Chapters 3 and 4. Of the remaining four examples cited by Batz, two are Connecticut, one is in California, and one is a bridge connecting New Jersey and Pennsylvania:

- Hartford, Connecticut. In 1982, the Connecticut state legislature eliminated the 45 cent (1989 dollars) toll for 3+ carpools using three bridges in Hartford, CT.* In addition, at one of these bridges, carpools were provided with an HOV bypass lane that they could use without stopping at the toll plaza.

- Merritt Parkway, Connecticut. In 1982, the Connecticut State legislature eliminated the 45 cent (1989 dollars) toll for 3+ person carpools using the Merritt Parkway. The legislature also specified that carpools be allowed to use a curb lane to bypass the three toll plazas during morning and evening peak periods. Carpools must slow to 5 mph at the plaza, but are not required to stop.

- San Diego, California. In 1977 the Coronado Bay Bridge in San Diego reduced its toll from $2.27 to 38 cents for 3+ person carpools, and from $4.74, $5.69, or $6.64 for commuter buses (all figures are in 1989 dollars).

- Delaware River Crossings. In 1972, four Delaware River crossings between New Jersey and Pennsylvania reduced tolls in 1989 dollars from $2.06 to $1.10 for 3+ carpools and vanpools and provided commuter buses with a 10 percent discount off the $4.12 and $2.75 toll (1989 dollars).

Preferential Parking Charges

All mode choice studies indicate that the mode choices of commuters are strongly affected by the level of parking charges. The significant cost of central area parking along with frequent transit service account for much of the higher levels of transit use by persons making trips to the CBDs of the nation's largest and densest cities. Given the demonstrated effectiveness of parking charges and incentives, it is surprising that so few efforts have been made to use taxes or surcharges on central area parking, other parking controls, or central area licenses to encourage more transit use and carpooling. In fact, as Pickrell (1980) has shown, parking policies in American cities are usually perverse and encourage greater use of private cars for commuting. Batz (1986, pp. E-11 to E-13) in his comprehensive survey of priority

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* All dollar figures, unless otherwise noted, are in constant 1989 dollars. Capital costs are adjusted to 1989 dollars using the ENR Construction Cost Index, operating and other costs using the GNP Implicit Price Deflator.

schemes could identify only two instances, one in San Francisco and one in Miami, where municipalities eliminated or reduced parking charges for vanpool and carpool users.

According to Batz (Ibid), Miami, Florida in 1975 reduced parking fees in a 200 space lot from $4.30 to $1.08 per day (1989 dollars) for 2+ carpools. Six year later, in 1981, authorities in the San Francisco Bay Area exempted 3+ carpools and vanpools from parking fees ranging from $3.40 to $9.51 per day (1989 dollars) for 60 park and ride lots (4,000 spaces) located along I-80. Enforcement problems proved to be a problem, however, and the free parking privilege was subsequently limited to vanpools.

The imposition of even rather small parking surcharges would have large effects on the use of private cars by commuters working in congested central areas and in many cases would provide large aggregate benefits to tripmakers. A Boston case study by Fauth, et.al. (1978, p. 204), for example, found that in 1975, a $1.08 (1989 dollars) parking surcharge on all non-residential parking places in the central area would reduce the number of less highly valued auto trips by 12 percent, would increase downtown transit trips by 17 percent, and would increase central area speeds by 52 percent.

The estimates of aggregate benefits from this modest surcharge were surprisingly large. Fauth, et.al. found that the $1.08 surcharge would have produced $52 million a year (1989 dollars) in aggregate net benefits in 1975, and that these benefits would grow to as much as $90 million per year (1989 dollars) by the end of the following decade. The authors concluded that one reason the impacts of the surcharge were so large was that a large fraction of commuters paid nothing to park in the central area in 1978; a $1.08 parking surcharge thus would have represented a very significant increase in the out-of-pocket expenses of these automobile users.

Exclusive Expressway Ramps

Strategically located bus-only ramps can also produce significant time savings at low cost. Batz (1986, p. E-21 to E-23) gives four examples of such ramps:

- Pittsburgh, PA. In 1971, Pittsburgh buses were provided with a bus-only ramp from Parkway Ave. to Parkway East during the morning peak period. The bus-only ramp was discontinued in 1983 when an HOV lane was implemented.

- Miami, Florida. In 1977, Florida officials provided a special ramp connecting a Miami park-and-ride lot to a concurrent flow preferential lane on I-95.

- Seattle, Washington. In 1970, Washington State DOT (WASDOT) provided an exclusive ramp for 2+ person carpools and buses from Cherry and Columbia Streets in downtown Seattle to a reversible median roadway reserved for carpools and buses.

Washington, D.C. In 1974, officials in Washington, D.C. implemented the South Capital Street Ramp for buses, taxis, and motorcycles outbound in the PM peak.

The bus-only ramps in Pittsburgh and Seattle are reported to have saved buses using them an average of 15 minutes and 5-10 minutes per trip respectively. The exclusive ramp connecting the Miami park and ride lot to a concurrent flow HOV lane on I-95 saved buses using it 0.8 minutes in the AM peak and 4.0 minutes during the PM peak. Carpools using the lane saved an average of 1.7 minutes in the AM peak and 2.1 minutes in the PM peak. Houston's extensive transitway system, described in Chapter 12, provides several bus-HOV ramps of this kind from its park and ride lots, located adjacent to freeways, to its transitways, which are normally located in the center of the freeway.

Separate Roadways

Even short stretches of bus-only streets or roads can provide transit users with large time savings. Some of the schemes are quite old and they are typically quite short. The oldest bus-only roadway for which we were able to obtain data is in Providence, R.I. In 1914, Providence officials converted the East Side Tunnel, an 0.8 mile, two lane facility, to the exclusive use of buses and emergency vehicles. The tunnel, which was originally constructed as a cable car right-of-way through the very steep College Hill, saves buses using it two to three minutes in comparison to alternative routes. In 1965 Providence opened a second, bus-only street, a one block long, one-lane bus-only roadway on Eddy Street.

Former exclusive streetcar right-of-ways have been converted to bus-only roadways in a number of cities. In St. Louis, Missouri, for example, the Modiamont Right-of-Way, a two-lane 3.5 mile bus-only street, was created from a former streetcar right-of-way in 1966. Similarly, officials in New Orleans, Louisiana, in 1962 implemented a two lane, 1.5 mile bus-only roadway on Canal Street. This 24 foot wide right-of-way was originally used by streetcars. Not all bus-only roadways are former streetcar right-of-ways, however. Brief descriptions of three others are provided below:

- San Antonio, Texas. Alamo Plaza was implemented as a 0.2 mile bus-only street in 1979. Buses using the street save about 2 minutes. Bus volumes are quite low, however. As a result planners in San Antonio are considering implementing a contra-flow bus lane. Alamo Plaza would then be made a pedestrian mall.

- Washington, D.C.. A .5 mile facility reserved for buses, taxes, motorcycles, and westbound right turns on New York Ave., N.E. was implemented in 1974.

- Chicago, Illinois. Canal Street at Union Street was converted to a 0.1 mile, four lane bus-only street in 1984.

Bus Priority on Arterial Streets

As Levinson (1987, p.1) points out, "HOV lanes on arterial streets are less glamorous but far more ubiquitous than HOV lanes on freeways." Noting that they are found in cities throughout the world, most commonly as a bus lane on downtown streets, he adds that priority lanes for carpools on arterial streets are less common, but that they can be found along several high-grade suburban arterials with near expressway standards.

Levinson (1987, p.6) estimated that "more than two hundred treatments (bus and carpool lanes) have been placed in operation." He finds that concurrent flow curb bus-lanes are by far the most common type of arterial street priority treatment, but that they are usually "least effective in terms of travel times saved." He adds "they are the easiest to implement and have the lowest installation costs, normally limited to pavement markings and signs, but that they are difficult to enforce and they impact curb access." Table 2-4 provides summary information on

Table 2–4. Existing and Proposed Normal–Flow CBD Curb Bus Lanes in 1973

City	Number of Streets	Dates Opened	Average Length (miles)	Average Peak Hour Buses	Comments
Operating in 1971					
Baltimore, MD	11	1958–63	0.40	30	Bus speeds up 21% AM, 87% PM
Birmingham, AL	1	1958	0.80	44	27% decrease in bus travel time
Buffalo, NY	2	1964–69	0.41	30	Bus lane protected by raised curbs
Dallas, TX	2	1958	0.63	75	370 buses per day in each lane.
Houston, TX	1	1971	0.87	65	1,270 buses per day.
Nashville, TN	5	1956–58	0.32	NA	5% reduction in bus running time.
Newark, NJ	1	1956	0.34	100	7 minute time savings
New York, NY	8	1969–71	1.60	87	22–42% reduction in bus travel time
Montreal, Canada	1	1966	0.06	17	Operates 24 hours per day
Peoria, IL	2	1959	4 blocks	NA	25% increase in bus speeds, 10% for cars
Providence, RI	2	1968	0.60	60	500 ft. between stops, 2 min. headways
Rochester, NY	2	1957–70	1.75	20	
San Francisco, CA	5	1970–71	1.00	37	Solid white line for length of lane
Syracuse, NY	3	1970	NA	NA	80 pk hr buses on street w/ two 8 ft. bus lanes
Vancouver, Canada	1	1963	0.50	40	Bus running time reduced 20%
Washington, D.C.	9	NA	0.52	82	
Winnipeg, Canada	1	1958	0.50	NA	Has police supervision
Proposed Lanes (with Year Proposed)					
Buffalo, NY	2	1972	0.47	NA	Proposed 24 hours per day operation
Charlotte, NC	2	1972	1.15	35	AM peak period only
Hartford, CT	3	1971	0.44	48	AM & PM peak periods
Pittsburgh, PA	10	1970	0.26	62	Downtown distribution for proposed busways
St. Louis, MO	7	1971	0.64	67	
Vancouver, Canada	1	1971	0.90	80	AM & PM peak periods
Washington, D.C.	2	1971	0.83	100	Same traffic controls as in exisitng lanes

Notes: All lanes allow rights turns, block no side streets, and have no special signal controls.

Source: Highway Research Board, "Bus Use of Highways, State of the Art," 1973.

64 concurrent flow curb bus-lanes that were operating in 17 North American cities in 1971, as well as information on 27 proposed concurrent flow bus-lanes in seven cities. As these data indicate, Baltimore (11 streets), Washington, D.C. (nine streets), and New York City (eight streets) appear to have made the most extensive use of bus-lanes in 1971. The data on average length indicate most bus-lanes are less than a mile long. New York City with bus-lanes on eight streets and an average length of 1.6 miles and Rochester, New York, bus-lanes on two streets with an average length of 1.75 miles are the exceptions.

Impressive travel time savings and speed improvements, shown in the "Comments" column, are reported for several of these facilities. Baltimore's 11 bus-lanes are credited with increasing bus speeds during the AM peak by 21 percent and during the PM peak by 87 percent. Newark, New Jersey's single entry, is credited with saving buses and bus users seven minutes per trip.

Contra-flow arterial street lanes, which are often implemented at the time cities introduce one-way street schemes, have fewer enforcement problems. Frequently, contra-flow bus-lanes are included in one-way schemes so that buses do not have to be re-routed. Contra-flow lanes often work better than concurrent flow bus-lanes on arterials because they are self-policing. Violators are more easily detected and motorists are less inclined to enter a bus lane when buses are approaching them from the opposite direction. Table 2-5 presents a listing of 23 contra-flow lanes. The length of these lanes range from 0.65 miles (Ward and Smithfield Streets in Pittsburgh) to 2.7 miles (College Street in Indianapolis). All but three are bus only lanes; the exceptions are a 1.9 mile contra-flow lane in Kalakava Boulevard in Honolulu and a 0.75 mile detour lane in Seattle which are also open to 3+ carpools, and a one mile long contra-flow lane in Madison, Wisconsin that is open to both buses and bicycles.

Preferential By-passes at Metered Ramps

In their study of current and planned high occupancy vehicle lanes, Southworth and Westbrook (1985) mention the numerous HOV freeway bypass lanes associated with freeway ramp metering schemes. In this regard, they make particular reference to the widespread use of metered ramps in Seattle, observing that "Seattle's I-5 system provides a good example of effective ramp metering". Citing a study by Betts, et.al. (1984), Southworth and Westbrook report that "metered ramps along I-5 have been adjusted to impose delays in the range of three to eight minutes on non-HOV bypass users, with very few violations of the metered signal rules taking place" (p. 4-5). WASDOT operates HOV bypass lanes for bus and 3+ carpools at six of the AM peak period ramps and one of the PM peak period metered ramps. Buses and carpools using these ramps save three to eight minutes per one-way commute over vehicles with fewer than three occupants. At the same time, about one-third of all bypass users are violators of the 3+ carpool rule, and 25 percent of HOVs using these ramps do not take advantage of the carpool and bus ramp bypasses.

Southworth and Westbrook (1985, p.4-5) add that southern California has by far the largest number of metered freeway ramps and associated HOV bypass lanes and observe that "such bypass lanes are reported to offer HOV users time savings of from three to eight minutes per one way commute." Chapter 9 provides a fairly extensive discussion of the use of ramp

Table 2–5. Principal Contraflow Lanes in the United States

Street and City	Year	Length	Users	Time Savings (Min.)	Comments
Market St., Harrisburg, PA	1957	3 blocks	Bus	NA	
Ft. Duquesne Blvd., Pittsburgh, PA	1960	0.1 miles	Bus	NA	
Canal St., Chicago, IL	1960–83	0.1 miles	Bus	NA	
Adams St., Chicago, IL	1960–83	1.0 miles	Bus	NA	
Jackson Blvd., Chicago, IL	1960–83	1.0 miles	Bus	NA	
University Ave., Madison, WI	1965	1.0 miles	Bus–Bikes	NA	In 1979, buses were moved to a parallel street, because of heavy bike traffic.
College St., Indianapolis, IN	1969	2.7 miles	Bus	NA	
5th St., Seattle, WA	1970	3 blocks	Bus	NA	5th St. lane provides access to an I–5 bus–HOV priority ramp.
Kalakaua Blvd., Honolulu, HI	1971	0.8 miles	Bus	NA	Lane was discontinued in 1984 because of several serious pedestrian accidents.
Kalanianaole Hwy, Honolulu, HI	1973	1.9 miles	Bus–3+HOV	2.9	Lane was bus only until 1975.
Miami, FL (Peak Periods)	1974	5.5 miles	Bus	11	Lane closed in 1976 because of high costs, despite 80+ buses using the lane daily.
Second Ave., New York, NY	1978	0.9 miles	Bus	10	
2nd & Marquette Aves., Minneapolis, MN	1978	1.0 miles	Bus	NA	
East 1st St., Austin, TX	1978	NA	Bus	NA	
Bridge Repair Detour, Seattle, WA	1978	.75 miles	Bus–3+HOV	NA	Detour lane will close when bridge repairs are completed.
Fifth Ave., Pittsburgh, PA	1979	0.3 miles	Bus	NA	
Hennepin Ave., Minneapolis, MN	1980	1.0 miles	Bus	NA	
Fifth Ave., Pittsburgh, PA	1980	1.6 miles	Bus	NA	
Penn Ave., Pittsburgh, PA	1980	0.5 miles	Bus	NA	Operation was stopped in 1984 because of LRT construction.
Madison & Washington Sts., Chicago, IL	1981	1.0 miles	Bus	NA	
Jefferson St., Toledo, OH	1981	12 blocks	Bus	3–4	12 block loop for buses and vehicles making turns.
Wood & Smithfield Sts., Pittsburgh, PA	1983	.65 miles	NA	NA	
Smithfield St., Pittsburgh, PA	1984	1.0 miles	NA	NA	

Source: Levinson, et al. (1973), Table 15.

meters and bus/carpool bypasses in Los Angeles. In providing an overall assessment of metered ramp and bypass systems Southworth and Westbrook (1985, p.4-6) conclude:

> While public acceptance of such metered ramp and bypass systems has been good in both Seattle and Los Angeles as well as in some corridors in Houston, San Francisco and Minneapolis, mixed response to ramp metering has occurred in Chicago and Dallas, with considerable hostility to the idea demonstrated in Atlanta.

Other Priority Schemes on Surface Streets

As we discussed previously, most route miles of transit operate in mixed traffic on general purpose surface streets. In fact, as Table 2-1 reveals, 96 percent of all directional route miles of public transit in the United States in 1986 were on general purpose streets. Schemes designed to improve bus speeds and reliability on these surface streets are thus of great importance. San Francisco's efforts in this regard illustrate some of the types of measures that can significantly improve the speed and performance of transit vehicles running on city streets.

Transit officials in San Francisco are particularly pleased with the results of a bus priority scheme they recently implemented on Stockton Street. The city constructed bus passenger loading platforms on four consecutive blocks. Use of these platforms, which extend out from the sidewalk to the right hand side mixed-flow traffic lane, have significantly reduced passenger boarding and unloading times and have thereby noticeably increased bus speeds.

UMTA also provided the city of San Francisco with a grant to implement various transit priority schemes on city streets. A traffic signal pre-emption scheme implemented at four intersections on Church Street has been one of the most successful of these measures. The four signalized intersections were chosen because: (1) transit vehicles were experiencing considerable delays; (2) most of the transit vehicles using them were electronically powered, either surface LRT or trolley buses (this meant the overhead power lines could be used for automatic vehicle detection); (3) overriding the normal signal timing would create only modest delays for traffic on the cross streets; and (4) there were no passenger boarding stops or signals between the point where the vehicle would be detected and the traffic signal that would be pre-empted. While the city has not completed a formal evaluation as yet, it seems clear that the use of signal pre-emption in this situation has reduced transit travel times without adversely affecting cross street travel at the four intersections. This contrasts with the experience in some other cities, where the results of signal pre-emption schemes by transit vehicles have been disappointing.

Church Street is also the focus of efforts by the City of San Francisco Planning Department to eliminate many unnecessary stop signs that currently adversely affect transit speeds and performance. Elimination of these stop signs has allowed buses to save on average 0.25 minutes at each intersection where a change was made. Though small individually, these savings add up for routes that have several unnecessary or poorly located stop signs (Robbins, 1988). Similar gains were made from better integrating the siting of transit stops and stop signs.

Before large numbers of bus stops were relocated, transit vehicles were frequently forced to "double stop" at many intersections. The problem typically arose when transit stops were positioned at the far side of intersections signed with the stop signs. City officials discovered they could significantly speed up transit operations in many cases by simply moving the transit stops to the near side (before entering) of the intersection. Transit vehicles using the relocated transit stop-intersections experienced significant time savings. In addition, relocation of the bus stops and reduction in the number of stops provided further benefits in the forms of less noise from accelerating buses and a smoother ride. As a preventive measure, the city implemented a new policy that requires the traffic engineer to consider the location of bus stops when he/she evaluates proposals to install new stop signs.

The San Francisco City Planning Department used still another UMTA grant to improve the coordination of bus stops and signal timings. Because they must frequently stop to load and unload passengers, transit vehicles making local stops travel at slower speeds than cars and trucks using the same streets. As a result, signal timing sequences that maximize the speeds and volumes of cars and trucks often adversely affect transit operations. Planning department analysts found that adjustments in signal times significantly improve average bus speeds on several San Francisco streets, with only modest impacts on other traffic.

Van Ness Avenue, one of the city's most heavily used two-way arterials, provides a good example of the gains from the bus stop-traffic signal timing coordination program. Three major bus routes use Van Ness Avenue, where the signal timing scheme is a "triple alternate," i.e. three consecutive signals turn green simultaneously, just as the next three turn red. This scheme provides a narrow band of green signals for traffic travelling at a constant rate of about 25 mph. Relocating the bus stops on Van Ness between the trios of alternative signals reduced the number of buses getting a red light at the second traffic light (in the triplet) by 82 percent and the number of buses getting a red light at the third light by 38 percent.

Conclusion

The preceding discussion describes just a few of the ways in which surface-level transit priority measures and better coordination between transit agencies and city planning and public works departments can improve transit performance on city streets. None of the measures in and of themselves are likely to have a decisive impact on transit speeds and performance, but if hundreds or even thousands of such opportunities are exploited, their cumulative impact on transit speeds, reliability, and ridership can be quite large.

The remaining chapters of this report provide more detailed evaluations of a number of the individual bus-HOV facilities referred to in this chapter. In addition to the discussion of the different experiences of a number of North American cities with bus-HOV priority schemes, several general issues are also addressed. In particular, various issues relevant to the bus vs. rail "debate" are developed, with attention being paid to common misconceptions about bus transit.

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Chapter 3. Bus Priority and Express Bus Operations in the New York Metropolitan Area

Introduction

New Yorkers are far more likely to use public transit than the residents of any other U.S. metropolitan area. Over 28 percent of the region's workers used public transportation (motor bus, rapid rail or commuter rail) to commute to work in 1980. In comparison, the percent of commuters using transit for their journeys to work in Chicago, the second highest metropolitan area, was only 16 percent, and the average transit mode split for the 10 largest metropolitan areas in the United States, exclusive of New York City, was nine percent (U.S. Census, 1986).

New York's dominance of the nation's rail rapid transit and commuter rail markets is even greater. Seventy-one percent of the nation's rail rapid transit boardings and 62 percent of its commuter rail boardings during 1985 were in the New York metropolitan area (UMTA, 1987). Rail rapid transit is also the region's most important transit mode. As the statistics in Table 3-1 reveal, over 53 percent of annual unlinked transit trips in the New York City metropolitan area were by rapid rail, of the balance, motor bus accounted for 41 percent and commuter rail five percent.*

The New York City Transit Authority (NYCTA), operator of the New York City subway and bus system, carried over 2.6 billion unlinked passenger trips (motor bus and rapid rail) in 1985, making it the metropolitan area's largest transit provider and far and away the largest transit operator in the nation. Combining ridership on other systems with those of the NYCTA, total unlinked annual transit trips in the greater New York City area exceeded 3.1 billion in 1985.

Transit's, and particularly rail transit's, importance to the New York region is widely recognized. However, the critical contributions of New York's bus operations, which carried approximately 1.3 billion annual unlinked trips in 1985, are less well understood and appreciated. The extent, scale, and performance of the region's trans-Hudson express bus operations is clearly one of the nation's best kept secrets. This chapter examines express bus operations in the New York metropolitan area and, in particular, the role of a number of important bus priority schemes that have provided cost-effective solutions to the problem of moving more than 121,000 inbound commuters each day (over 36 million annual transit trips) between the outlying, suburban and exurban parts of the region and the Manhattan CBD.

The New York metropolitan area is the site of one of the nation's earliest and most significant bus priority schemes. Implemented in 1970, the XBL (the inbound, AM contra-flow exclusive bus lane on New Jersey's I-495 from the New Jersey Turnpike to the Lincoln Tunnel) is the most significant bus priority operation in the New York City metropolitan region and arguably in North America. Other New York metropolitan area bus priority facilities include a contra-flow bus and taxi lane in Queens on the Long Island Expressway (I-495) approach to the Queens Midtown Tunnel, a contra-flow bus and taxi lane on the Gowanas Expressway

* Unlinked passenger trips are transit boardings. A single "linked" trip may entail the use of two or more vehicles (i.e. bus-rail-bus) or transfers between vehicles of the same type and thus may consist of two or more boardings.

Table 3–1. Boardings and Annual Passenger Miles For the New York Metropolitan Area's Major Transit Providers

Transit System	Mode	Annual Boardings (000's)	Annual Pass. Miles (000's)	Average Weekday Pass.Trips	Pass. Per Rev. Mile	Ave. Trip Distance (Miles)
New York CTA	MB	1,023,245	1,999,271	3,445,270	10.67	2.0
N.J Transit Co.	MB	130,009	1,252,299	437,739	2.15	9.6
New York Green Bus	MB	30,269	91,441	101,917	5.57	3.0
NJTC	MBP	24,557	205,330	82,682	2.05	8.4
Jackson Hgts–Tri.	MB	21,949	35,051	73,903	5.48	1.6
Queens Transit	MB	14,001	49,246	47,140	2.90	3.5
Steinway Transit	MB	7,744	20,798	26,074	2.68	2.7
New York Jamaica	MB	7,424	31,925	24,998	3.35	4.3
N.J Transit Co.	MBP	7,416	22,812	24,969	1.38	3.1
NJ Suburban Trans	MB	3,727	141,458	12,549	0.54	38.0
NJ Hudson Transit	MB	1,284	38,516	4,323	0.37	30.0
New York CTA	RR	1,561,487	6,491,122	5,257,531	5.67	4.2
New York PATH	RR	53,619	254,191	180,536	4.74	4.7
NJ Port Auth. TC	RR	10,231	89,613	34,447	2.72	8.8
New York LIRR	CR	74,928	2,157,026	252,283	1.51	28.8
N.Y. MTNR	CR	51,958	1,431,851	174,942	1.70	27.6
N.J Transit Co.	CR	34,341	781,787	115,625	1.15	22.8
N.J Transit Co.	CRP	1,903	57,679	6,407	0.60	30.3
N.Y. MTNR	CRP	1,052	44,375	3,543	0.61	42.2
N.J Transit Co.	SC	3,163	6,000	10,651	5.80	1.9
Total	MB	1,271,625	3,888,147	4,281,564	6.25	3.1
Total	RR	1,625,337	6,834,925	5,472,514	5.60	4.2
Total	CR	164,182	4,472,718	552,801	1.43	27.2
Total	SC	3,163	6,000	10,651	5.80	1.9
Total	ALL	3,064,307	15,201,790	10,317,530	5.03	5.0

Code: MB–Motor Bus, RR–Rapid Rail, CR–Commuter Rail, SC–Street Car
Note: A P at the end of code indicates private carrier.
Source: UMTA, "Section 15, 1985 Annual Report," August, 1987.

north in Brooklyn at the approach to the Brooklyn Battery Tunnel, a concurrent-flow HOV lane in New Jersey at the western approach to the George Washington Bridge, and a HOV priority lane at the New Jersey entrance to the Holland Tunnel. Table 3-2 lists these facilities along with their length, the number of buses served, and average daily ridership. A striking characteristic of these and similar schemes is their limited length. As these data indicate, the combined length of all these schemes is less than 10 miles.

None of the region's bus priority schemes listed in Table 3-2 operate during the PM commute period in the outbound direction.* This reflects the heavy concentration of employment in the Manhattan CBD and the lower level of peaking that occurs during the PM period (Konecnik, 1988). PM congestion is simply less serious and as a result there is less justification for such bus priority schemes during the afternoon and evening hours.

Commuting Into Manhattan

Employment in the New York City metropolitan area is heavily concentrated on the island of Manhattan and particularly the Manhattan CBD, at the southern end of Manhattan (south of 60th street). In spite of continuing dispersal, 28 percent of the region's 6.7 million jobs were located in the Manhattan CBD in 1980 (U.S Bureau of Census, 1980). As the data in Table 3-3 reveal, moreover, 3.4 million persons entered the Manhattan CBD on a typical workday in 1987. Nearly half of these person trips, over 1.5 million, took place during the morning peak period (7-10 AM) and over 83 percent of person trips entering the CBD during the AM peak period were by public transit. Over 61 percent of the peak period person trips were on rapid rail, either the NYCTA subway or PATH (Port Authority Trans Hudson Rapid Rail), nine percent on buses, and 17 percent in private automobiles or taxis.

Table 3–2. Bus Trip and Vehicle Volume on Selected Bus Priority Schemes into Manhattan

Scheme	Length in miles	Buses	Average Daily Riders
Trans Hudson Schemes			
XBL–Lincoln Tunnel	4.00	1,904	69,100
Holland Tunnel	0.33	132	3,991 (1)
GW Bridge	1.10	66	2,112 (1)
Subtotal Trans–Hudson	5.43	2,102	75,203
Other Schemes			
LIE Contraflow	2.20	377	13,864 (2)
Gowanus Contraflow	0.90	431	19,198 (2)
BQE Blue Lane	1.20	300	13,000 (2)
Subtotal Other Schemes	4.30	1,108	46,062
Total All Schemes	9.73	3,210	121,265

Note: Data is for latest year available. Most data are for typical workdays in 1988.
(1) Includes HOV passengers
(2) Includes taxis
Sources: NYCDOT (1985), NYCDOT (1988), Port Authority NY & NJ (1987).

* The recently implemented (May 1989) North Hudson Busway (on the New Jersey side of the Hudson River) is the first priority scheme in the metropolitan area that is operational during the afternoon peak period. Only rough estimates of North Hudson Busway ridership were available at the writing of this report so it is not listed in Table 3-2. However, it is described in the last section of this chapter.

While bus passengers accounted for only nine percent of trips entering the Manhattan CBD, there were nonetheless nearly 141,000 inbound bus trips during each AM peak period.* Of particular interest to us here is that nearly half of all bus riders entering the Manhattan CBD during the AM peak period used Lincoln Tunnel buses (Table 3-4).

The data in Table 3-3 do not separately identify ferry trips, which are combined with commuter rail and Roosevelt Island tramway boardings. In October 1987, there were 11 ferry routes providing service to the Manhattan CBD. Eight of those routes originated in New Jersey, one in Brooklyn, and two in Queens, including one from LaGuardia Airport. Average daily ridership (both directions) on these routes was 3,608 or approximately 1,800 person trips per day into the CBD (NYCDOT, 1989). While they still account for a tiny fraction of trips, the ferries have registered impressive percentage gains: daily ferry ridership into the CBD increased by 59 percent between October 1987 and October 1988. As of April 1989, the Manhattan CBD was served by 18 ferry routes with a total daily ridership of 5,800. In spite of the impressive percentage increase in the number of ferry commuters, ferry commuting represents a minuscule portion, less than one tenth of one percent, of trips into the CBD.

Manhattan is an island, separated from the other four New York City counties and New Jersey by the Hudson, East, and Harlem Rivers. A significant fraction of persons working in Manhattan live in New Jersey or in New York City's two most populous boroughs, Brooklyn (population 2.2 million in 1980) and Queens (population 1.9 million in 1980) (U.S. Census, 1984). As Figure 3-1 indicates, auto and bus trips to Manhattan from New Jersey, Queens and Brooklyn must use one of ten river crossings. The Lincoln and Holland Tunnels and the George Washington Bridge serve commuters from New Jersey to Manhattan; the Queensboro and Triboro Bridges and the Queens Midtown Tunnel connect Queens to Manhattan; and the Manhattan, Brooklyn, and Williamsburg Bridges and the Brooklyn Battery Tunnel serve Brooklyn. These crossing are heavily congested during peak periods and experience serious congestion throughout much of the rest of the day.

As Table 3-4 indicates, the four bridges and four tunnels that provide direct vehicle access to the Manhattan CBD (the Queensboro, Manhattan, Brooklyn and Williamsburg Bridges and the Lincoln, Holland, Queens-Midtown, and Brooklyn-Battery tunnels) served more than 250,000 persons and 95,000 vehicles during the AM peak period (7-10 AM) in 1987. The George Washington and Triboro Bridges, which enter Manhattan at points three to four miles north of the CBD, do not provide direct access to the CBD. Forty-three percent of bridge and tunnel person trips into the CBD during the morning peak were made by bus, even though buses comprised only three percent of all entering vehicles. Even though auto occupancy rates are relatively high by the standards of other areas, autos using these critical river crossings still carry only 1.6 persons per car.

The data included in Table 3-4 thus demonstrate that buses use only a small fraction of the capacity of the bridges and tunnels serving Manhattan, that extensive bus ridership greatly increases the person carrying capacity of the facilities, and that express bus services are an essential part of commuter services to downtown Manhattan. Further support for these conclusions is provided by the data in Table 3-5, which give the percentages and total

* In the case of linked, multi-modal trips, trip makers in these comparisons are assigned to the mode they used to enter the CBD, i.e. the mode used to cross the CBD corridor.

Table 3–3. Inbound Person Trips to the Manhattan CBD by Mode During the Entire Day and the AM Peak Period

Mode	Number 24 Hours	Number 7–10 AM	Percentage 24 Hours	Percentage 7–10 AM
Public Transit				
Rapid Rail	1,737,379	934,849	50.9%	61.3%
Bus	249,364	140,826	7.3	9.2
CR–Ferry–Tram	270,096	193,933	7.9	12.7
Subtotal	2,256,839	1,269,608	66.1	83.3
Autos and Taxis	1,158,495	254,975	33.9	16.7
Total	3,415,334	1,524,583	100.0	100.0

Source: "HUB Bound Travel, 1987," NYMTC, September, 1988.

Table 3–4. Vehicles and Persons Entering the Manhattan CBD During the AM Peak (7–10 AM)

Crossing	Vehicles Bus	Vehicles Autos & Taxis	Vehicles Total	Persons Bus	Persons Autos & Taxis	Persons Total
New Jersey						
Lincoln Tunnel	1,904	12,798	14,702	69,100	18,614	87,714
Holland Tunnel	132	7,946	8,078	3,991	10,217	14,208
Total	2,036	20,744	22,780	73,091	28,831	101,922
Queens						
Queens Midtown Tunnel	377	11,204	11,581	13,864	17,852	31,716
Queensboro Bridge	58	17,547	17,605	1,831	26,528	28,359
Total	435	28,751	29,186	15,695	44,380	60,075
Brooklyn						
Brooklyn Battery Tunnel	431	9,896	10,327	19,198	19,207	38,405
Brooklyn Bridge	0	11,406	11,406	0	16,786	16,786
Manhattan Bridge	10	8,661	8,671	408	13,296	13,704
Williamsburgh Bridge	16	12,870	12,886	706	20,833	21,539
Total	457	42,833	43,290	20,312	70,122	90,434
All	2,928	92,328	95,256	109,098	143,333	252,431

Source: "Hub Bound Travel, 1987," NYMTC, September, 1988.

Figure 3-1. Entry Points to the Manhattan CBD

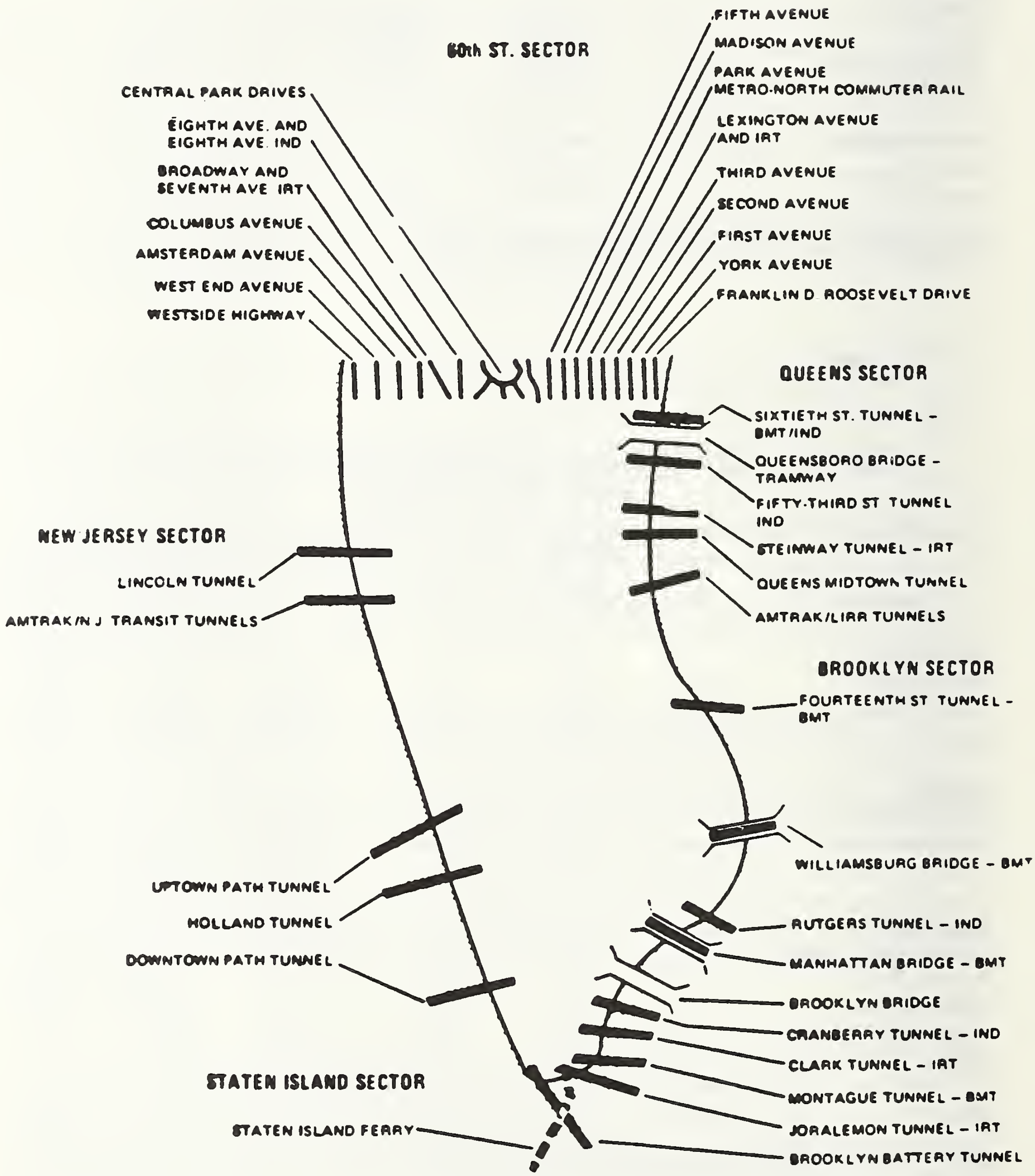

Table 3–5. Percent of Vehicles and Persons Entering the Manhattan CBD During the AM Peak Period (7–10 AM)

Crossing	Vehicles Bus	Vehicles Autos & Taxis	Vehicles Total	Persons Bus	Persons Autos & Taxis	Persons Total
New Jersey						
Lincoln Tunnel	2.0%	13.4%	15.4%	27.4%	7.4%	34.7%
Holland Tunnel	0.1%	8.3%	8.5%	1.6%	4.0%	5.6%
Queens						
Queens Midtown Tunnel	0.4%	11.8%	12.2%	5.5%	7.1%	12.6%
Queensboro Bridge	0.1%	18.4%	18.5%	0.7%	10.5%	11.2%
Brooklyn						
Brooklyn Battery Tunnel	0.5%	10.4%	10.8%	7.6%	7.6%	15.2%
Brooklyn Bridge	0.0%	12.0%	12.0%	0.0%	6.6%	6.6%
Manhattan Bridge	0.0%	9.1%	9.1%	0.2%	5.3%	5.4%
Williamsburgh Bridge	0.0%	13.5%	13.5%	0.3%	8.3%	8.5%
Total	3.1%	96.9%	100.0%	43.2%	56.8%	100.0%

Source: "Hub Bound Travel, 1987," NYMTC, September, 1988.

numbers of vehicles and persons using crossings to reach the Manhattan CBD during the AM peak period by facility.

The bus priority schemes currently operating in the New York City metropolitan area were designed to encourage greater use of bus transit by persons travelling into the Manhattan CBD during the AM peak period, and particularly to increase the effective capacity of the four bridges and four tunnels that provide direct connections to the Manhattan CBD. Metropolitan area transportation planners and administrators hoped to achieve increased bus commuting by reducing bus travel times and by increasing the reliability of express bus services. These schemes have reduced travel times and increased reliability by segregating buses from other traffic and by permitting them to bypass points of especially serious congestion.

Testing the Limits of Bus Rapid Transit

The trans-Hudson corridor from New Jersey to Manhattan is, and has long been, one of the nation's most heavily travelled urban corridors. In 1967, over 412,000 persons crossed the Hudson from New Jersey into Manhattan on a typical weekday. As the data in Table 3-6 indicate, more than half, 52 percent, of all trips were by public transit (rail and bus); 62 percent of **transit** trips were by bus and 38 percent were made by rail.

By 1986, inbound trans-Hudson travel had grown nearly 40 percent relative to 1967, to over 576,000 persons per day, and the transit and auto shares had become the opposite of the 1967 splits, i.e. 52 percent auto and 48 percent bus. Even so, inbound transit trips increased by over 28 percent from 215,000 per day in 1967 to more than 276,000 per day in 1986. As a result

Table 3–6. Average Daily Trans–Hudson Person Trips by Mode for Selected Years, 1967–1986

Facility	Mode	Number 1967	Number 1976	Number 1986	Percentage 1967	Percentage 1976	Percentage 1986
Path	Rail	61,426	68,800	97,000	14.9%	15.3%	16.8%
	CR	20,750	24,400	35,000	5.0%	5.4%	6.1%
Total	Rail	82,176	93,200	132,000	19.9%	20.8%	22.9%
Lincoln	Bus	109,018	96,429	119,800	26.4%	21.5%	20.8%
Holland	Bus	2,521	1,960	7,500	0.6%	0.4%	1.3%
GW Bridge	Bus	21,066	15,767	16,800	5.1%	3.5%	2.9%
Total	Bus	132,605	114,156	144,100	32.2%	25.4%	25.0%
Lincoln	Auto	50,751	65,405	77,400	12.3%	14.6%	13.4%
Holland	Auto	29,595	36,412	41,450	7.2%	8.1%	7.2%
GW Bridge	Auto	117,073	139,750	181,350	28.4%	31.1%	31.5%
Total	Auto	197,419	241,567	300,200	47.9%	53.8%	52.1%
Total	Transit	214,781	207,356	276,100	52.1%	46.2%	47.9%
Total	All	412,200	448,923	576,300	100.0%	100.0%	100.0%

Source: Port Authority NY & NJ, 1987.

Table 3–7. Typical Peak Period (7–10AM) Weekday Eastbound Trans–Hudson Passengers

Facility	Mode	Number 1967	Number 1976	Number 1986	'Percentage 1967	Percentage 1976	Percentage 1986
Path	Rail	43,711	48,600	67,000	24.2%	26.8%	28.3%
	CR	11,916	13,700	21,400	6.6%	7.5%	9.1%
Total	Rail	55,627	62,300	88,400	30.8%	34.3%	37.4%
Lincoln	Bus	62,655	55,775	70,800	34.7%	30.7%	29.9%
Holland	Bus	837	1,227	3,800	0.5%	0.7%	1.6%
GW Bridge	Bus	10,992	5,641	5,500	6.1%	3.1%	2.3%
Total	Bus	74,484	62,643	80,100	41.3%	34.5%	33.9%
Lincoln	Auto	12,561	15,135	18,100	7.0%	8.3%	7.7%
Holland	Auto	4,178	5,630	8,700	2.3%	3.1%	3.7%
GW Bridge	Auto	33,674	35,830	41,100	18.7%	19.7%	17.4%
Total	Auto	50,413	56,595	67,900	27.9%	31.2%	28.7%
Total	Transit	130,111	124,943	168,500	72.1%	68.8%	71.3%
Total	All	180,524	181,538	236,400	100.0%	100.0%	100.0%

Source: Port Authority NY & NJ, 1987

of a major capital improvement program for PATH that dramatically increased service quality and led to a 58 percent increase in PATH ridership, the bus share of all trans-Hudson transit trips fell from 62 percent in 1967 to 52 percent in 1986. Even so, trans-Hudson bus ridership grew by over eight percent during the 20 year period, reaching more than 144,000 eastbound trips per day in 1986.

Transit carries an even larger share of peak period trips. As the data in Table 3-7 indicate, over 71 percent of the 236,400 persons crossing the Hudson into Manhattan during the morning peak period (7-10 AM) in 1986 used public transit, about half of them used bus and half used rail. These data also show that 88 percent of all trans-Hudson bus passengers used Lincoln Tunnel buses to reach midtown Manhattan. Of the 12 percent that did not use the Lincoln Tunnel buses, close to five percent used Holland Tunnel buses to reach the west side of lower Manhattan, and nearly seven percent used George Washington Bridge buses to reach areas on the Upper West Side.

Table 3-7 also reveals that more than three quarters of 1986 trans-Hudson rail passengers, i.e. 76 percent, rode PATH trains from New Jersey to downtown, primarily to the World Trade Center and stations south of 33rd street; the remaining 24 percent took commuter rail to Penn Station, which is located in midtown, at 33rd Street and 7th Avenue.

Trans-Hudson passenger and vehicle traffic are expected to grow significantly in the near future (URS, 1987, p. 2-1). Projections prepared by the Port Authority of New York and New Jersey indicate that the number of eastbound peak period trans-Hudson commuters is expected to grow by nearly 50,000 between 1985 and 1990; over 80 percent of these new commuters are expected to use public transit and over 37 percent are expected to use buses (Table 3-8).

The Lincoln Tunnel Bus Priority Scheme

The data presented above on trans-Hudson travel make it clear that the Lincoln Tunnel and related facilities are highly critical parts of the region's rapid transit system. One of the most significant and successful bus priority schemes in North America operates from the western New Jersey approach to the Lincoln Tunnel, through the tunnel, and finally to the Port Authority Bus Terminal (PABT) at 40th street in midtown Manhattan. The 4-mile Lincoln Tunnel bus priority scheme between New Jersey and midtown Manhattan consists of five inter-related components:

a. The XBL, a 2.5-mile contra-flow bus lane on I-495 in New Jersey connecting the New Jersey Turnpike and the Lincoln Tunnel. The lane operates only during the AM peak period in the eastbound (peak) direction, with operations commencing at 6:30 AM and ending at approximately 10 AM, depending on traffic conditions. The contra-flow lane is reserved for unibody, for-hire ICC (Interstate Commerce Commission) registered vehicles with a capacity of 16 or more passengers;

b. Exclusive toll lanes with automatic vehicle identification (AVI) on the New Jersey (west) side of the Lincoln Tunnel;

Table 3–8. Actual (1985) and Projected (1990) Trans–Hudson Person Trips and Percentage Changes

Facility	1985	1990	% Change 1985–1990
Bus			
Lincoln Tunnel*	72,460	87,010	20.1%
Holland Tunnel	2,830	3,980	40.6%
GW Bridge	5,170	6,290	21.7%
Bus Total	80,460	97,280	20.9%
Rail			
Path (WTC&33)**	63,100	80,010	26.8%
Commuter Rail	18,800	21,630	15.1%
Rail Total	81,900	101,640	24.1%
Auto			
Lincoln Tunnel	17,460	17,930	2.7%
Holland Tunnel	8,600	8,890	3.4%
GW Bridge	40,160	48,150	19.9%
Auto Total	66,220	74,970	13.2%
Transit Total	162,360	198,920	22.5%
Total	228,580	273,890	19.8%

*: Most Lincoln Tunnel buses use the XBL contraflow; some buses enter Lincoln Tunnel from local streets.
**: WTC = World Trade Center; 33 = 33rd Street Path Station.
Source: URS Company, "Midtown Remedies," May 1987

c A 1.5 mile bus-only lane through the Lincoln Tunnel;

d. Bus-only ramps connecting the east end of the Lincoln Tunnel to the PABT; and

e. The Port Authority Bus Terminal located at 40th Street and 8th Avenue on the west side of midtown Manhattan.

Buses from New Jersey make the four mile trip in about 12.5 minutes averaging just under 20 mph between "teardrop" entry points at the beginning of the XBL lane to the PABT (Gonseth, 1988).* The 20 mph express bus speeds, which compare favorably with the average automobile speed in the corridor during the AM Peak period of approximately eight mph, translate into approximately 18 minutes of time savings for the average trans-Hudson bus passenger.

Trans-Hudson priority bus operations are by no means new. Recognition of the importance of the Lincoln Tunnel express bus operations, which was evident more than 35 years

* Nearly all XBL buses have the Port Authority Bus Terminal as their final destination; as Table 3-9 reveals, 79 percent of XBL passengers use the PABT, 16 percent are discharged on Manhattan streets, and four percent have final destinations outside of Manhattan.

ago, led to construction in 1950 of the PABT on Manhattan's east side at 40th Street, one half mile east of the eastern terminus of the Lincoln Tunnel. Bus rapid transit only began to realize its full potential, however, when the third tube of the Lincoln Tunnel was opened in 1957. With the completion of the third tube it became possible to allocate an entire peak-direction lane to buses during peak periods. It took an additional 13 years before the final critical link of the Lincoln Tunnel bus priority scheme, the XBL, began operations. The history of its planning and implementation are discussed below.

Implementation of the XBL

In December 1963, the Port Authority of New York and New Jersey released a study proposing an exclusive contra-flow bus lane at the New Jersey approach to the Lincoln Tunnel. At the time, the tunnel was carrying 400-500 buses per hour in the peak direction during peak periods and there were long bus queues at the tunnel entrance during the morning peak. The Port Authority was already operating an outbound "exclusive bus lane" in the evening, i.e. bus only ramps from the PABT to the entrance of the Lincoln Tunnel. These bus-only ramps enabled New Jersey bound buses to bypass congested New York City streets and thereby avoid the serious delays that had previously plagued outbound buses during the afternoon peak period.

After considering several alternatives, the Port Authority study recommended taking an I-495 outbound (west) general traffic lane for use as an inbound (east) exclusive contra-flow bus lane during the morning peak period. This led to field tests focusing on the effect of proposed contra-flow lane operations on freeway safety, speeds, and capacity in both the peak and off-peak directions.

The XBL, i.e. the I-495 contra-flow lane, was finally implemented in December 1970, seven years after the Port Authority study. Informed observers suggest that opposition by New Jersey's Department of Transportation (DOT) was the principal cause of the delay (Goodman, 1988). There were no operational contra-flow freeway bus lanes in the United States or elsewhere in the world at that time, and the New Jersey DOT had legitimate reasons to be concerned about the safety of the proposed facility. The Shirley Highway Busway, discussed in Chapter 7, had been operating safety since 1969, but it consisted of two barrier separated reversible express lanes.

In 1970, John Kohl, a transportation engineer from the University of Michigan, was appointed Commissioner of Transportation for the State of New Jersey and became Chairman of the Tri-State (New York, New Jersey and Connecticut) Transportation Commission. Kohl had been persuaded of the merits of contra-flow freeway express bus lanes after reading a paper written by Nathaniel Cherniack. Cherniack's (1963) paper urged transportation engineers to be more transportation and less traffic oriented and, in particular, to be more sensitive to mass transportation and the potential benefits of preferential treatment of buses on highways (Goodman, 1988). Less than three months after he was named commissioner, Kohl was able to implement the XBL project on an experimental basis. To achieve this result, Kohl by-passed regular staff at New Jersey DOT, who continued to oppose the XBL, and used his position on the Tri-State Transportation Commission to promote the project.

Kohl and the New Jersey DOT, in conjunction with the Tri-State Transportation Commission, the Port Authority of New York and New Jersey and the New Jersey Turnpike Authority, implemented the XBL lane as a one-year demonstration project.* After one year of safe and successful operation, the XBL was designated a permanent facility.

The XBL project quickly achieved its twin objectives of improving bus travel time and reliability in the trans-Hudson corridor and of attracting more riders. During the morning peak hour the XBL saved bus riders an average of more than 10 minutes over pre-XBL travel times (Goodman, 1972, p.47). A Tri-State Regional Planning Commission (1972, p.24) survey found, moreover, that 95 percent of XBL bus riders felt the XBL significantly reduced the variability of their trip and 86 percent felt the trip was more enjoyable .

Improvements in bus speeds, reliability and comfort led to increased ridership; peak period ridership on bus routes using the XBL grew by six percent (2,300 persons) during a period when transit ridership in the metropolitan area as a whole was declining (Goodman, 1972, p.46).** An analysis of the period 1968-1971 by the Tri-State Regional Planning Commission (1972, p.20) indicated that the time savings and other service improvements provided by the XBL arrested a mild downward trend in short haul bus trips from New Jersey to the Manhattan CBD (from locations near the entrance to the tunnel) and spurred increases in medium and long haul patronage.

The overall impact of the XBL on transit mode splits and ridership in the corridor is less clear-cut. During the first year of XBL operation, only four percent of new bus users reported that they had been auto drivers or passengers, 90 percent had switched from PATH, and 3 percent had not previously made the trip (Altshuler, 1979, p.371). Even so, the performance of the 2.5 mile contra-flow lane was quite impressive. During the AM peak period, the single XBL lane carried nine times as many people as each of the three, peak-direction eastbound highway lanes, and at a significantly higher speed.

Implementation of the XBL apparently had little or no effect on other expressway users. A survey of traffic conditions in several sections of I-495 during the first year of XBL operations revealed little deterioration in westbound traffic conditions that could be attributed to the contra-flow bus lane; westbound traffic continued to average 30-40 mph through the morning peak period.*** In addition, any declines attributable to contra-flow lane operations were of relatively minor consequence because of the limited length of roadway used by the XBL (Goodman, 1972, p.62).

The Lincoln Tunnel priority scheme has been an unqualified success. It demonstrates that a properly designed bus rapid transit scheme can accommodate very high vehicle and

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* The project was implemented in three months. It was administered by the Tri-State Transportation Commission, and was funded by a $1.67 million (1989 dollars) federal grant from the U.S. Department of Transportation's Urban Corridor Program. At Tri-State's request, the Port Authority's staff supervised the project and the Port Authority maintained and operated the bus lane. This arrangement exploited the Port Authority's knowledge obtained from planning and testing the bus lane and its experience in operating reversible roadways, such as the Lincoln Tunnel Center Tube.

** NYCTA rapid rail ridership declined by four percent between 1970 and 1971 (Pushkarev and Zupan, 1980, p. 308).

*** There was a 35 mph speed limit imposed on westbound (off peak direction) I-495 when the XBL was operational. (The 35 mph speed limit still applies during XBL operations).

passenger volumes. The lane was used by more than 700 buses and 25,000 - 30,000 bus commuters each day when it first opened in 1971 and volumes increased steadily to the point where more than 1,600 buses and more than 58,000 bus passengers per day used the XBL in 1987.* Actual and projected XBL passengers by origin and destination are shown in Table 3-9. The single XBL (I-495) contra-flow lane now carries 10 times as many people as each of the three inbound, with-flow, general traffic lanes. As Table 3-10 indicates, the XBL, which is

Table 3–9. XBL Passenger Volumes 7–10 AM Eastbound

	Number		Share		Percent
	Actual	Projected	Actual	Projected	Change
	1985	1990	1985	1990	1985–1990
Origin					
NJ Turnpike N	17,420	20,220	30.6%	29.8%	16.1%
NJ Turnpike S	22,245	27,655	39.1%	40.7%	24.3%
Route 3	14,655	17,085	25.8%	25.1%	16.6%
Other	2,551	2,964	4.5%	4.4%	16.2%
Destination					
PABT	44,960	54,560	79.0%	80.3%	21.4%
CBD Non–PABT	9,360	10,400	16.4%	15.3%	11.1%
Long Haul	2,370	2,400	4.2%	3.5%	1.3%
Total	56,690	67,360	100.0%	100.0%	18.8%

Source: URS Company, "Midtown Remedies," May 1987

Table 3–10. Actual and Projected Buses Using the Lincoln Tunnel/XBL During the Peak Hour (7:40 to 8:40 AM) by Segment

	Actual		Projected		Percent Change	
Segment	1983	1986	1990	2005	1986–1990	1986–2005
XBL						
Turnpike/Exit 17	235	266	290	368	9.0%	38.3%
Route 3	154	174	190	241	9.2%	38.5%
Turnpike/Exit 16	281	317	346	439	9.1%	38.5%
Total	670	757	826	1,048	9.1%	38.4%
Local Approaches	109	123	134	170	8.9%	38.2%
Total Through Lincoln Tunnel	779	880	960	1,218	9.1%	38.4%

Source: Martin, et. al. "Hudson Waterfront Transitway System," May 1988.

* Not all Lincoln Tunnel buses use the I-495 contra-flow lane (the XBL). As a result, the number of bus trips using the XBL during peak periods is less than the total number using the Lincoln Tunnel during peak periods.

currently operating near maximum capacity, accommodates over 750 buses during the peak hour (7:40 to 8:40 AM).

The XBL operation is frequently cited as the best example of bus rapid transit's potential and cost effectiveness. It is difficult not to be impressed. Peak period inbound passenger volumes on the XBL, 58,000 in 1987, exceed those of any other bus rapid transit facility in North America by a large margin. In addition, only five rapid (heavy) rail transit lines carry as many passengers as the XBL during peak periods, all five are part of the New York City subway system (Pushkarev and Zupan, 1980, p. 311). Further perspective is provided by the fact that BART (Bay Area Rapid Transit) carried only 25,700 persons to San Francisco through its transbay tube during the AM peak period in 1987, less than 50 percent of the bus ridership of the Lincoln Tunnel priority scheme and WMATA's (Washington, D.C.) much touted Blue-Orange line carried only 13,000 persons during the AM peak period in 1980, 25 percent of Lincoln Tunnel bus ridership (Charles River Associates, 1988, p.4-9).

Characteristics of the XBL

The 2.5 mile long XBL, shown in Figure 3-2, originates at the western end of I-495 and the eastern spur of the New Jersey Turnpike and continues to the Lincoln Tunnel Toll Plaza on the New Jersey side of the Hudson River. The XBL, which carries buses eastbound to the Lincoln Tunnel Toll Plaza and operates only during the AM peak period, takes a lane from westbound I-495.

As Figure 3-2 shows, the XBL has two single lane western access ramps in Secaucus, one from New Jersey Turnpike Interchange 16E to the south and the other from Turnpike Interchange 17E to the north. The north (Interchange 17E) ramp also provides access for buses from Route 3, from the North Bergen Park and Ride lot, and from non-turnpike points (where buses use a western slip ramp to merge with the turnpike ramp at Interchange 17).

There is no metering or other form of controlled access to the XBL. The "teardrop" configuration of these specially constructed ramps, with their sharp radii and two merge points, effectively limits the numbers of buses accessing the XBL lane. The teardrop ramps have been widened in recent years to increase traffic flow (URS, 1987, p.4-2). Enforcement is provided by the Port Authority and New Jersey Turnpike police stationed at the two access ramps.

The Port Authority is responsible for operating and maintaining the XBL. Annual operating expenses were $629,000 (1989 dollars) in 1987, including the costs of placing and removing the polyvinyl posts used to mark the lane each day (Gonseth, 1988).* The Port Authority uses "surplus" bridge and tunnel toll revenues to pay for XBL operations. XBL project

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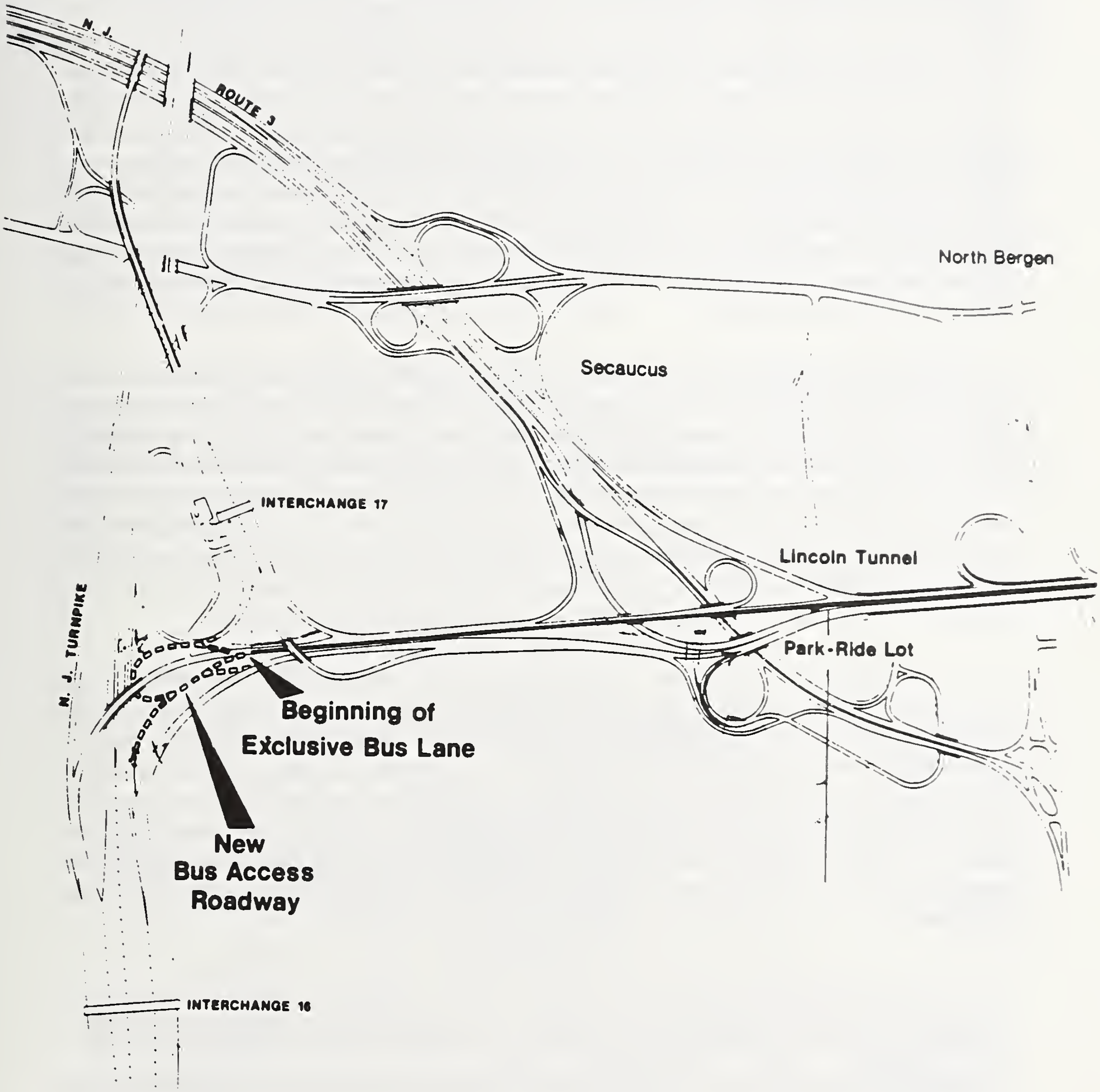
* The contra-flow lane is designated by approximately 80 lane directional signals and signs on overpasses and bridges along the westbound side of I-495. These signals, placed over the center of each lane, show a green arrow pointing downward when the lane is open for traffic and a red "X" when the lane is closed. Holes have been drilled in the pavement for more than 350 cylindrical 1-1/2 feet high, bright yellow polyvinyl chloride traffic posts, which are placed at 40 foot intervals for the entire 2-1/2 mile length of the bus lane when it is operational. The posts, which separate the eastbound from the westbound traffic (there is no buffer lane throughout most of the XBL), are manually placed each morning before the lane is opened to buses and are then removed at the end of the morning peak period.

Figure 3-2.

Schematic of XBL from NJ Turnpike to Lincoln Tunnel



management and operations are handled by the Port Authority's Tunnels, Bridges and Terminals Department as part of Port Authority's Lincoln Tunnel operations.

Total XBL capital costs are difficult to estimate. Our best estimate of total capital costs of the contra-flow lane is $5.59 million in 1989 dollars.* This figure includes $1.31 million in project development funds provided by the U.S. Department of Transportation, $3.94 million for the permanent control system (shared by several agencies), and $310,000 for the teardrop bus access roadways which were built and paid for by the New Jersey Turnpike Authority.

The XBL contra-flow lane ends at the Lincoln Tunnel Toll Plaza where XBL buses enter the center tube of the Lincoln Tunnel. Completion of the third tube in 1957 increased the total number of tunnel lanes from four to six and the Lincoln Tunnel's vehicular capacity by roughly 50 percent. As mentioned previously, the third tube also facilitated reversible, 4-2 operation of the tunnel; the new two-lane center tube is used by inbound vehicles in the morning and outbound vehicles at night. Completion of the third tube, moreover, created a mismatch between tunnel and roadway capacity on I-495, the main approach to the tunnel. Before the XBL was implemented, the four eastbound Lincoln Tunnel lanes were fed by three regular flow lanes of I-495 during the AM peak period.

XBL buses are able to bypass much of the congestion at the Lincoln Tunnel Toll Plaza. During the AM peak period, the two leftmost lanes of the 13 Lincoln Tunnel toll area lanes are allocated to exclusive bus use, both for local New Jersey buses and buses from the XBL.** Buses with "non-stop toll stickers" affixed to their windshields can bypass the toll booths and proceed to the left lane of the center tube of the tunnel which is reserved for their use. Bus stickers are read by automatic vehicle identification equipment with optical scanners; as a result, buses do not have to stop but simply pass through the toll plaza at speeds of between 30 to 40 mph. Bus companies using the Lincoln Tunnel are billed at the end of each month by the Port Authority.***

The capacity of the Lincoln Tunnel exclusive bus lane has been estimated at 1,270 buses an hour, each travelling at 30 mph. This figure includes both XBL buses and buses from local streets that enter the toll plaza from a separate local bus lane. With its peak hour volume of approximately 900 buses, the Lincoln Tunnel exclusive bus lane currently operates at Level of Service (LOS) C during most of the peak period. Port Authority analysts do not anticipate that Lincoln Tunnel capacity will constrain trans-Hudson bus trips to midtown in the near future. As Table 3-10 indicates, they project a peak hour bus demand at the Lincoln Tunnel of 960 buses per hour in 1990; this is well below the estimated capacity of one lane of the center tube at Level of Service C.

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* Unless otherwise noted, all dollar amounts are in constant 1989 dollars. Capital cost values are converted into 1989 dollars using the ENR Construction Cost Index, while operating and other costs are adjusted using the GNP Implicit Price Deflator.

** The total number of toll booths has been increased over the years as part of continuing efforts to improve traffic flow into the tunnel (URS, 1987, p. 4-2).

*** The Port Authority together with the Triboro Bridge and Tunnel Authority want to move towards a single metropolitan area wide AVI system for all bridges and tunnels in the metro area. Under such a system all vehicles with appropriate identification could be "optically identified" and billed monthly for their use of the bridges and tunnels. The Port Authority is currently carrying out an AVI demonstration program for trucks licensed in the metropolitan area.

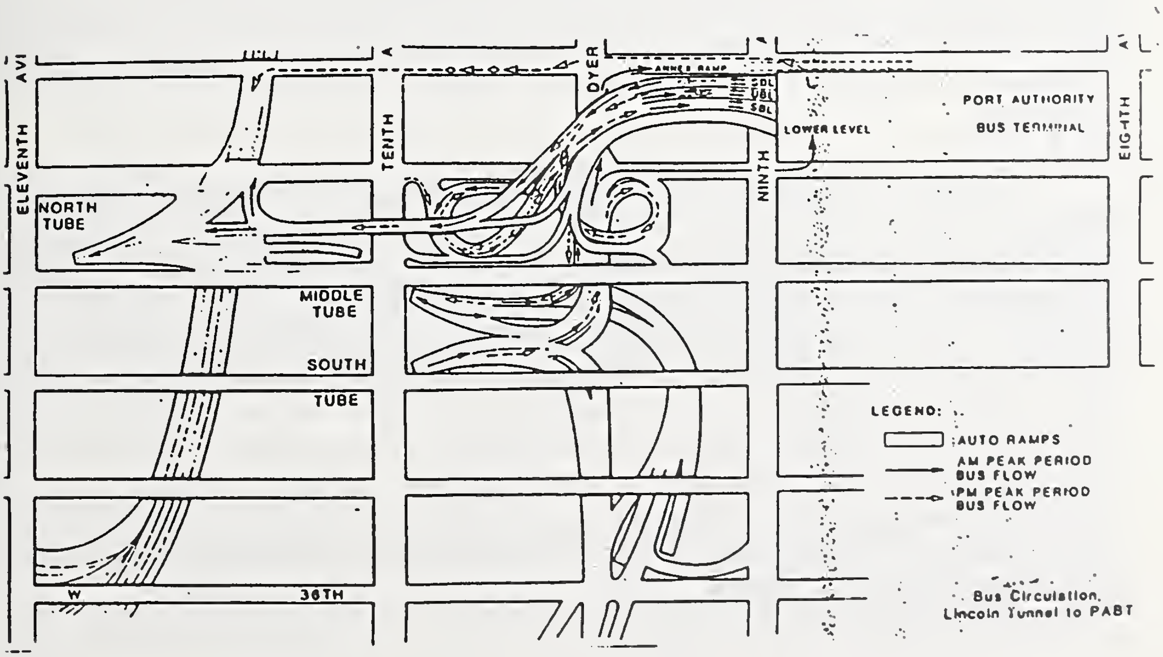
Bus-only ramps from the eastern (Manhattan-side) terminus of the Lincoln Tunnel to the PABT (shown in Figure 3-3) enable XBL buses to avoid congested midtown Manhattan streets. These ramps take buses directly from the tunnel to the Upper (UBL) or Suburban (SBL) Levels of the PABT, to unloading platforms along 40th Street or, in the case of buses headed uptown, to a left turn lane at Eighth Avenue.

The PABT was completed in 1950 at a cost of $216 million in 1989 dollars ($24 million at the time in) as part of a cooperative effort by the City of New York and the Port Authority to reduce bus volumes on CBD streets and to improve bus service to midtown. The new terminal reduced travel times for bus trips using the facility by between six and 30 minutes, depending on time of day and the final destination (Danielson and Doig, 1982, p. 198).

At the time the proposal for the Port Authority bus terminal was first made in 1944, over 1,500 trans-Hudson buses entered mid-Manhattan streets on a typical day. Most of the Lincoln Tunnel buses discharged passengers at eight private bus terminals scattered between 34th and 51st street on Manhattan's west side. The Port Authority estimated that the single major terminal near the Lincoln Tunnel removed more than two million miles of bus travel from midtown Manhattan annually (Danielson and Doig, 1982, p.199).

Port Authority analysts, relying on bus counts collected in 1985 and 1986, estimate the combined inbound capacity of the UBL and SBL ramps at approximately 1,150 buses per hour. (Capacity of the SBL ramp is estimated at 680 buses per hour, while the UBL ramp is rated at 470 buses per hour). Observation of these ramps indicates current bus volumes are being accommodated without much difficulty and that the ramps should not be bottlenecks for the foreseeable future.

Figure 3-3. Bus Ramps from the Lincoln Tunnel to the PABT



The suburban and upper bus levels of the PABT are used primarily for commuter bus loading and unloading and have limited space for parking buses. The UBL has 25 sawtooth berths (where each bus has a designated loading and unloading area) and 32 pull-through platforms (where buses discharge passengers along a platform adjacent to enclosed passenger waiting areas). The north wing of the UBL is used for bus parking and has space for 48 buses. The SBL has 60 pull-through platforms in the main terminal area and 26 sawtooth berths in the north wing with no space for bus storage. The Lower Bus Level of PABT is used mostly for long haul, not commuter, buses and has 67 berths, most of which are sawtoothed.

The PABT's sawtoothed berths can accommodate about six buses per hour, while the terminal's platform berths can handle between four and five buses per hour depending on the equipment used (the number of doors is the principal factor which determines unloading time). The Port Authority also supplements the designated unloading platforms with "non-designated" bus berths on the SBL and UBL for "overflow unloading." These additional berths can accommodate 135 and 108 buses per hour respectively. Thus, the UBL and SBL have practical peak capacities of 326 and 276 buses per hour respectively, or about 600 commuter buses an hour.

The Port Authority Bus Terminal capacity is being severely tested by growing Trans-Hudson bus use. With approximately 700 buses an hour currently using the Lincoln Tunnel during the peak period and approximately 900 during the peak hour (750 from the XBL and approximately 150 from local streets near the N.J. entrance to the Tunnel), the PABT has become the weak link in the maintenance of reliable, high-speed trans-Hudson express bus operations. Expansion of the PABT has not kept up with demand and the terminal's capacity is well-below current demand.

A shortage of passenger unloading space is by no means the Port Authority Bus Terminal's only problem. There is very limited space to park buses in the PABT or in the surrounding area. As a result, many XBL buses must deadhead back to New Jersey (go back without any passengers) in the morning and then deadhead back to the PABT for the PM peak period. This deadheading increases operating costs significantly, and of course, contributes to congestion, particularly in the inbound (eastern) direction of I-495 before and during the PM peak period.

The PABT is obviously a critical component of the Lincoln Tunnel bus priority scheme. Without the bus terminal and its links to CBD mass transit, (downtown) distribution of trans-Hudson bus riders would be problematic. When XBL bus passengers arrive at the PABT, they may either walk to their final destinations in midtown or transfer to New York City subways or buses. The PABT has direct connections to NYCTA subways that permit trans-Hudson bus users to board 6th, 7th and 8th Avenue express and local uptown and downtown subway trains and a crosstown shuttle service without entering city streets. Because of these convenient access links, the 42nd Street stations of the 6th Avenue, 7th, and 8th Avenue subway lines, with 34,500, 78,950 and 44,600 boardings per day respectively, are three of the subway system's most heavily patronized stations (Pushkarev and Zupan, 1980, p. 328). The PABT's convenient links to New York City's subways are clearly a major factor in the success of the XBL-Lincoln Tunnel-PABT express bus scheme.

As we discuss in our subsequent analysis of the East River bus priority schemes, there is nothing comparable to the PABT on Manhattan's East Side. As a result, express buses from Brooklyn, Queens and Long Island must unload their passengers on city streets. This use of city streets by express buses from Queens and Long Island, of course, increases bus passenger trip times and contributes to congestion on Manhattan streets. Problems of downtown distribution for express bus users and serious congestion along major avenues in New York City, particularly on Madison and 5th Avenues, are important factors in limiting the potential of express bus transit into Manhattan from northern, eastern, and southern points.

Trans-Hudson Express Bus Services

The State of New Jersey became deeply involved in bus transit in 1970 as part of an emergency program of operating support designed to save numerous private companies from bankruptcy and to maintain crucial New Jersey transit services. The emerging program became permanent and the state ultimately acquired the largest private operator, Transport of New Jersey, in 1980 (Jane's, 1987, p. 266).

At the present time, the state-owned New Jersey Transit (NJT), which is considered one of the nation's most effective public bus operators, operates its own fleet of buses and commuter rail and also coordinates, subsidizes and contracts-out services to private operators.* In fiscal year 1986, NJT carried 136 million passengers at fare levels that were sufficient to cover over 66 percent of operating expenses, as compared to a national average of under 40 percent (Jane's, 1987, p. 267).**

Even with NJT's acquisition of some private companies during the 1980's, a significant portion of it's services are provided through contract by private operators. In fact, about a third of New Jersey Transit's bus passengers are carried by private operators. Approximately 150 private operators received subsidies from NJT in 1987. Many private operators belong to associations for the coordination of schedules on shared routes, and in a few cases, for the pooling of revenues.

Most of the private bus operators using the XBL receive some form of subsidy. Many of the XBL express buses are provided on lease to private operators at nominal rates and New Jersey Transit also provides direct operating subsidies to some private operators. The Port Authority also subsidizes some XBL bus services. Most of the subsidized private operators of XBL express buses collect their passengers on residential streets in suburban areas (Phraner, 1988). The use of multiple private operators, along with the flexibility inherent in bus transit, has provided an effective matching of supply and demand of commuter services along the corridor served by the XBL.

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* New Jersey Transit was selected by the American Public Transportation Association as North America's best transit agency in 1984-85.

** Recently NJ Transit has experienced growing budget deficits. In March 1989, NJ Transit proposed raising bus and rail fares 12.5 percent and cutting back services to cover a projected 1990 budget deficit of $55 million (New York Times, March 1, 1989, p. B 1-2).

Recent Developments

The Lincoln Tunnel priority scheme is currently being used at, or beyond, its capacity; as a result, bus travel times have steadily increased and reliability has declined. As Table 3-10 indicates, approximately 900 buses used the Lincoln Tunnel during the peak hour (7:40 to 8:40 AM) in 1986 and more than 750 of these used the XBL lane. These levels exceed the PABT's effective capacity and Port Authority analysts estimate they are about seven percent greater than the XBL's "ideal" capacity. As a result, buses using the XBL during the peak hour are often forced to queue-up at entry points. Some spreading of peak period travel has occurred, but not enough to prevent serious delays.

Delays rarely occurred when the XBL was being used by 650-680 buses an hour.* To provide an "acceptable" level of service on the contra-flow lane, maximum peak hour bus volumes must be kept below 700. When hourly XBL volumes exceed 700 an hour, extensive bus queuing occurs, extending to and past both New Jersey Turnpike Toll Plaza I6E and I7E (URS, 1987, p.3-2). This condition has existed since 1986.

Trans-Hudson bus commuters, even those using the XBL, now regularly experience delays of 15 to 20 minutes. Heavy peak hour use of the contra-flow lane has led to backups at the tear-drop and excessive bus delays have caused New Jersey Turnpike police to divert buses to the I-495 inbound general traffic lanes, where they experience delays of up to 20-30 minutes (URS, 1987, p.3-2). These deteriorating conditions have led to public complaints and has focused media attention on the worsening "trans-Hudson commuting problem". Growing numbers of XBL bus users have contacted elected officials and public agencies urging governmental action and suggesting a variety of relief measures. Private bus operators have also experienced growing complaints and increasing operating costs, as fewer buses are able to make second runs during the peak period. They too have begun pressing for governmental action (New Jersey Register, 1987, p. 1423).

As Table 3-10 indicates, Port Authority analysts expect peak hour bus demand at the Lincoln Tunnel will continue to grow, reaching levels in excess of 1,200 buses per hour by 2005. In the absence of corrective action, the growing problems encountered by XBL buses and commuters will steadily worsen.

The Trans-Hudson to Midtown Transit Task Force

A task force organized by the Port Authority in 1985 made a number of proposals to alleviate trans-Hudson congestion to the Manhattan CBD; its interim and long term recommendations include the following.**

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* The XBL's maximum flow rate has been observed at 68 buses in five minutes or 36,000 passengers per hour, assuming 45 passengers per bus.

** The Task Force also recommended improvements in the PATH rapid rail transit service, including new PATH cars and stations; new trans-Hudson passenger ferry services; direct bus service to New York City's financial district (Wall Street) from park and ride lots in New Jersey; a PM peak period eastbound bus lane for buses returning to the PABT for the outbound peak, and improvements in bus and HOV access to the Holland Tunnel. These recommendations are not considered in this report.

Interim Improvements:

- Increase the capacity of the XBL by temporarily using an eastbound lane of I-495 as a concurrent-flow three or more persons per vehicle (3+) HOV lane during the AM peak period; and

- Extend XBL contra-flow operations 1.5 miles further west on Route 3.

Long Term Improvements:

- Implement three new busways, the North, North Hudson, and South Busways, to augment corridor bus capacity and relieve congestion on the XBL.

The most controversial proposal would have implemented an eastbound concurrent-flow carpool and bus lane on I-495. The proposed concurrent HOV lane, referred to as "Lane 3" and "XBL II", would have begun 2.5 miles from the Lincoln Tunnel Toll Plaza (close to the teardrop access point to the XBL) and ended at the entrance to the tunnel, where buses and 3+ carpools from the proposed Lane 3 would have shared the right lane of the center tube with trucks and cars. The scheme would thus have functioned as a "queue-jumping" mechanism for eastbound buses and carpools.

The proposed Lane 3 scheme would have augmented corridor capacity for express buses by allocating more freeway lanes to buses and carpools. Express buses would have been able to use either the bus-only XBL or the concurrent flow HOV lane. The effect of implementing Lane 3 on XBL volumes would have depended on how many buses shifted to Lane 3, which would in turn would have depended on travel conditions in the concurrent flow lane. The level of service achieved by Lane 3 would have depended on the number of 3+ carpools.

The Lane 3 scheme would have provided XBL express buses with significant operational benefits. Buses from the North Bergen Park and Ride and from Exit 16E of the New Jersey Turnpike would have continued to use the XBL, while buses and carpools from Route 3 would have used Lane 3. As part of managing use (balancing volumes) of the two priority lanes, buses from New Jersey Turnpike Exit I7E could have been re-routed to Lane 3 via Route 3, if the XBL contra-flow lane became congested.

Port Authority computer simulations of the probable impacts of the proposed Lane 3 operation indicated that queues would develop and delay vehicles at the entrances from the southbound New Jersey Turnpike and Route 3. The same simulations indicated that a Lincoln Tunnel delay-free express bus service could only be achieved with an HOV lane that began on Route 3 and merged directly into Lane 3. The consultants therefore recommended providing an additional 1.5 mile HOV segment starting at the interchange of Routes 3 and 495 (URS Inc., 1987).

The simulations also suggested that the Lane 3 scheme would reduce the travel times for New Jersey express bus commuters to Manhattan by about 20 percent. Carpools would benefit even more than express bus users as their travel times would decline by 45 percent on

average. At the same time, travel times for low occupancy vehicles and trucks would increase by about 30 percent, or approximately 15 minutes (URS, 1987, p. 4-7).

While the Lane 3 proposal was supported by commuters, private operators and NJ Transit officials, it was strongly opposed by many New Jersey developers, businesses, and local officials who feared it would cause backups on Route 3 and degrade access to development sites in the New Jersey Meadowlands and along the New Jersey waterfront.

In February 1989, the Commissioner of the New Jersey Department of Transportation, Hazel Gluck, announced the Lane 3 proposal would <u>not</u> be implemented and gave the following reasons:

- Recent job growth in the New Jersey side of the Hudson, and the Wall Street crash in October 1987 appear to have temporarily slowed the growth of trans-Hudson commuting and to have reduced the number of buses using the existing bus lane during peak hours to manageable levels;* and

- Concern that Lane 3 would cause significant delays for automobile commuters and truckers travelling to sites in eastern New Jersey, including Hudson County and the Meadowlands (<u>The New Jersey Star Ledger</u>, February 9, 1989, p. 50).

While concerns about the level and distribution of future growth in the metropolitan area clearly played a role in the decision to abandon plans for Lane 3, there were other factors as well. Many of the officials who were advocates of Lane 3 recognized that in spite of its substantial benefits, Lane 3's implementation would be problematic. Port Authority project managers expected high violation rates and difficulties in enforcement, since there would be no physical separation and no shoulder to stop and ticket violators. They also anticipated some adverse public reaction to the "taking away" of a general traffic lane on I-495 eastbound with resulting increases in travel time for low occupancy vehicles.

There was also concern that Lane 3 might be too heavily used, with the result that the facility would operate at levels below the desired Level of Service C. Of course, if too many carpools and violators used Lane 3, the time savings projected for buses using the lane would not have materialized and The New Jersey DOT would have been forced to consider raising the threshold for carpools to four or more persons per vehicle.

The 3+ carpool criteria was originally proposed to conform with the definition used by the Port Authority in its discount carpool commuter ticket program for all Port Authority bridges and tunnels. Under the carpool discount program started in the mid-1970's, high occupancy auto commuters can purchase "script" toll books for less than 50 percent of the regular $3.00 round trip toll (1989 dollars).**

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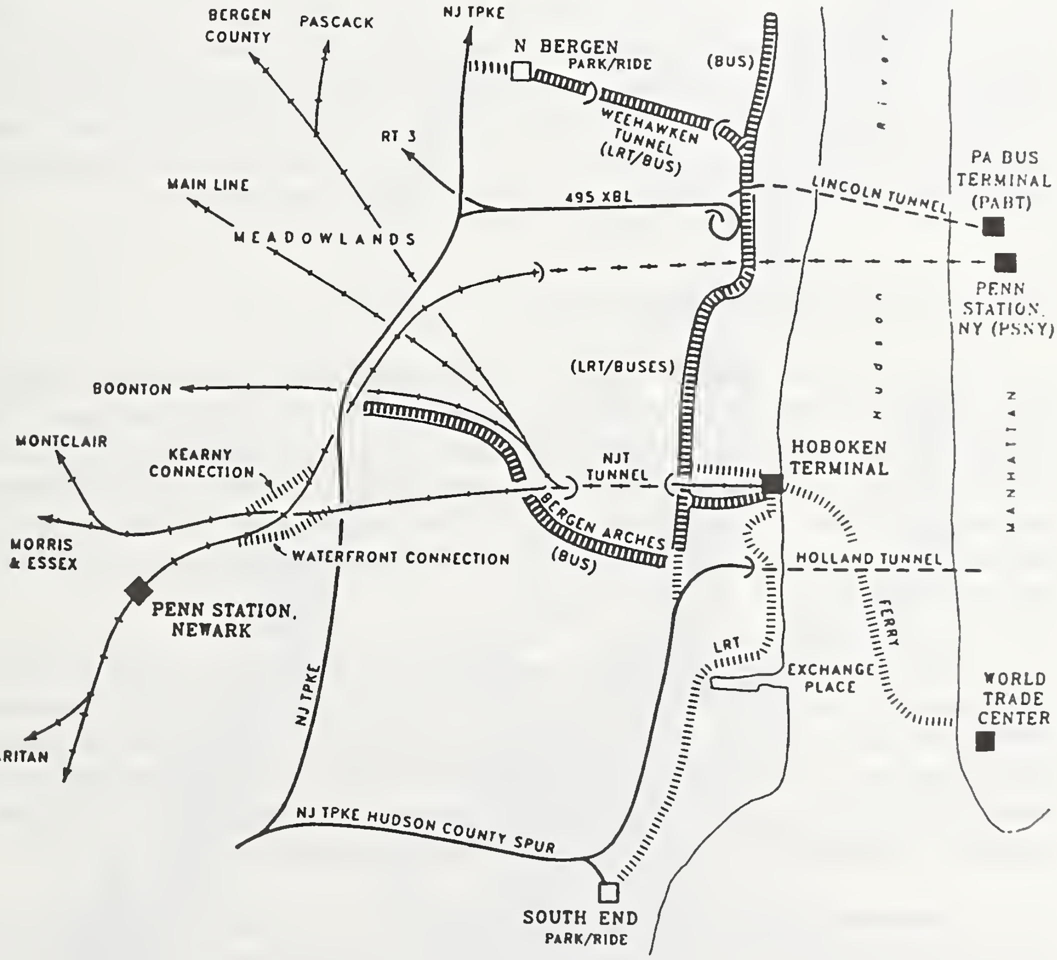
* According to NJDOT the number of buses using the XBL lane during the busiest hours had declined to 620 by 1989. While Commissioner Gluck attributed the decline to external demand factors, Frank Gallagher, president of the New Jersey Motor Bus Association, argued the reduced use was the result of "the last several years of chronic delays" (<u>The New Jersey Star-Ledger</u>, 1989, p.50).

** The Port Authority also offers commuter books for all vehicles good on Port Authority trans-Hudson bridges and tunnels. Discounts on non-HOV commuter books are only 15 percent less than the discounts for HOV commuter books. The Port Authority encourages the use of commuter books because they reduce service times at toll plazas and thereby increase capacity. When the NJDOT announced its decision to drop plans for Lane 3, it recommended the "immediate elimination of discounted

Long-Term Proposals

If the projected long term increase in trans-Hudson traffic to midtown Manhattan actually occurs, the growth in bus use will strain existing facilities to the breaking point. In an effort to both improve existing conditions and allow for anticipated growth, the Port Authority, New Jersey DOT, and New Jersey Transit proposed building three busways as part of a comprehensive Hudson River waterfront transportation plan. The proposed Weehawken North and South Busways, shown in Figure 3-4, would provide permanent relief for the XBL by providing alternative high-speed bus links for express buses from the south and north to the Lincoln Tunnel. The North Hudson Transitway, which began operations in May 1989, has improved bus services to the northern portion of Hudson County, a rapidly growing residential area.

Figure 3-4. Planned Busways and LRT in the New Jersey Hudson Corridor



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toll rates for automobile commuters using the Port Authority's Hudson River bridges and tunnels" as an "alternative" measure to reduce automobile traffic through the Lincoln Tunnel during rush hours (The Star-Ledger, 1989, p. 51).

As presently proposed, the North Busway would provide a new exclusive transit facility from the New Jersey Turnpike to the Lincoln Tunnel for buses originating at points north of the XBL and Route 3. As Figure 3-4 reveals, there would be an exclusive busway between the New Jersey Turnpike and North Bergen; buses would then share a converted Weehawken Tunnel with a proposed light rail line.* Another bus-only link would connect the Weehawken Tunnel to the Lincoln Tunnel. New Jersey DOT is currently negotiating with Conrail to purchase the Weehawken Tunnel right-of-way. It is generally acknowledged that the North Busway could not be completed before 1996 because of the time required to relocate the Conrail tracks and to convert the Weehawken Tunnel to bus and rail use.

An alternative proposal would use ferries to bypass both the XBL and the Lincoln Tunnel. Buses using the North Busway would be ferried from a new terminal at the eastern end of the Weehawken Tunnel to a new terminal built on a pier on Manhattan's west side. The ferryboat scheme has been suggested as a "Lincoln Tunnel reliever" that would provide additional capacity, if, and, when it becomes impossible to squeeze more trips through the Lincoln Tunnel.

In the proposed South Busway scheme, also shown in Figure 3-4, buses originating at points south of the XBL would use the New Jersey Turnpike Hudson County Spur to reach the South Busway, an exclusive busway that would intercept a proposed bus-LRT transitway running from a point just south of the Hoboken Terminal to the Lincoln Tunnel. A longer term proposal would provide an East-West busway along the Boonton Line and Bergen Arches right-of-way from the New Jersey Turnpike to the South Busway in Hoboken.

Hudson Waterfront Transportation Plan

The North and South Busways are part of the larger Hudson Waterfront Transportation Plan prepared by the Port Authority with the New Jersey DOT and New Jersey Transit. In addition to the two busways, the plan envisions an LRT line, shown in Figure 3-5, and a boulevard, which would both run along the waterfront. Light rail vehicles and buses would operate on adjacent, but separate, right-of-ways from the west end of the Weehawken Tunnel to just south of Hoboken Terminal. They would, however, share a common right-of-way in the Weehawken tunnel.

Development of the New Jersey waterfront is one of the main, perhaps even the primary, objectives of the Hudson Waterfront Transportation Plan. As a result, the plan provides only very limited connections between the LRT and the proposed waterfront boulevard and the North and South Busways. Connections between the busways, the LRT, and the waterfront boulevard would be limited to a few transfer points well to the south, north, and west of the New Jersey waterfront area targeted for development by private developers and the Port Authority.

Advocates of the waterfront plan fear that the benefits of locating on the New Jersey side of the Hudson River, mainly lower transportation and access costs, would be reduced if transit services to the Jersey waterfront were combined with transit services to Manhattan. As a result,

* The arrangement would be similar to the joint bus-LRT Mount Washington transit tunnel in Pittsburgh, which is discussed in Chapter 7.

Figure 3-5.

Planned Transitway Facilities
In the NJ Hudson Corridor

most supporters of the scheme envision using the busways and the XBL to provide long haul bus rapid transit from outlying areas in New Jersey to Manhattan and to a few LRT Stations on the Jersey waterfront. The LRT and the new waterfront boulevard, in turn, would serve the Jersey waterfront.

Capital costs in 1989 dollars of the Hudson Waterfront Transportation Plan are currently estimated at $1.27 billion. As the data in Table 3-11 indicates, 1989 dollar construction costs of $1.01 billion include $429 million for the 12.7 mile of waterfront LRT; $236 million for the waterfront boulevard and local access roads; $40 million for 9.3 miles of busways; and $309 million for the 4.5 miles of shared bus-LRT transitway from the west end of Weehawken Tunnel to Hoboken Terminal (Phraner, 1988). These data indicate that the per mile cost of the proposed LRT in 1989 dollars is more than seven times the per mile cost of the proposed busway, $33.8 million a mile for the LRT vs. $4.3 million per mile for the exclusive busway. The $309 million ($68.6 million per mile) cost of the bus-LRT transitway includes the cost of converting the 4,200 ft. Weehawken Tunnel to a two-way, two-lane transit tunnel (we have no basis for allocating the joint tunnel conversion costs between LRT and the busway). The remaining cost items are $94 million for right-of-way requisition and $161 million for engineering and design.

The ROW cost estimates assume that developers will "donate" right-of-way along the New Jersey waterfront. Private developers have been enthusiastic supporters of a waterfront LRT and have strongly affected transportation planning for the area through conditional donation of right-of-way (dependent on the use of right-of-way for fixed guideway rapid transit).

Other Express Bus Priority Schemes

First proposed in 1985, the North Hudson Transitway (NHT) commenced operations in May 1989. The NHT is a dedicated 2.7 mile transitway. It operates largely on exclusive right-of-way (formerly Conrail right-of-way). In contrast to the other bus priority schemes operating in the metropolitan area, the NHT operates during both the morning and afternoon peak periods.

The NHT, as shown in Figure 3-5, runs from the junction of River and Hillside Roads in West New York, at the foot of the Palisades, to the vicinity of the Lincoln Tunnel toll plaza in Weehawken. It serves areas north of the Lincoln Tunnel improving trans-Hudson services for commuters from northern Hudson and southeastern Bergen counties. Projected time savings for bus routes using the facility were estimated to range from 1.3 to 14.7 minutes (NJDOT, 1987). The NHT is projected to serve 122 bus trip during the morning commute period and 113 in the afternoon peak period. In addition, the facility is projected to serve 136 buses during the morning and evening peak periods that are deadheading to and from the Manhattan CBD to the Weehawken bus terminal (NJDOT, 1987).

The second most important bus priority scheme in the New York metropolitan area after the XBL, at least in terms of the numbers of bus riders served per day, is a one-mile, inbound contra-flow lane on the Gowanas Expressway at the Brooklyn (southern) approach to the Brooklyn Battery Tunnel (BBT). The Gowanas Expressway contra-flow lane was established in October 1980 for the exclusive use of buses and taxis. It takes the off-peak direction median

Table 3–11. Length, Capital Costs and Costs Per Mile of Proposed NJ Waterfront Project by Segment
(All Dollar Figures Are in Millions of 1989 Dollars)

Component	Length (Miles)	Cost	Cost Per Mile
Construction			
LRT	12.7	$429	$33.8
Busway	9.3	$40	$4.3
LRT/Busway	4.5	$309	$68.6
Blvd.	NA	$236	
Total	NA	$1,014	
ROW	NA	$94	
Engineering	NA	$161	
Total	NA	$1,269	

Source: Martin et. al. (1988).

lane away from general traffic; as a result, there are four inbound lanes and two outbound lanes during the AM peak period.

Buses and taxis use a break/slip in the median of the highway to gain access to the contra-flow lane. The lane which operates only during the AM peak period (7-10 AM) saves buses and taxis an average of 20 minutes in travel time. Both public and private bus carriers use the facility. The largest number of buses using the Gowanas Expressway contra-flow lane, originate in Brooklyn, with the remainder from Staten Island.

Buses may also use a .75 mile concurrent-flow bus lane that is open during the AM peak period on the Gowanas Expressway south of the contra-flow lane. The so called "Blue Lane" (named for the markings on the roadway which designate it) is a bus-only acceleration lane for buses merging onto the Gowanas.

Bus use contributes substantially to the number of persons served by the Brooklyn Battery Tunnel during the AM peak period. As the data in Table 3-4 indicate, an average of 19,000 passengers and 430 buses entered downtown Manhattan via the BBT during the AM peak period in September 1987. Most of these buses used the Gowanas Expressway contra-flow lane. During the AM peak period, buses carried the same number of passengers through the BBT as autos, but were only four percent of total vehicles. The bus mode split during the peak hour (8 and 9 AM) is even more impressive; in this one hour period, BBT buses carried 44 percent more people than autos (9,701 vs. 6,742) and comprised only six percent of total vehicles (NYMTC, 1988, p. 32-33, 36).

With the success of the Gowanas contra-flow lane and the Blue Lane in inducing bus ridership from Brooklyn and Staten Island to downtown Manhattan, and the continued congestion at the approach to the BBT, the New York City DOT is now evaluating the possibility of lengthening the contra-flow lane by an additional four miles. The New York City DOT is also considering implementing a PM peak period contra-flow lane.

Holland Tunnel HOV Lanes

The overwhelming majority, i.e. 92 percent, of individuals using transit for trans-Hudson trips to lower Manhattan (primarily the Wall Street area), ride PATH to the World Trade Center (NYMTC, 1988, p.32-33). Potential benefits from Holland Tunnel bus priority schemes are much less than they are for Lincoln Tunnel schemes. This results, to a significant degree, from differences in the physical characteristics of the two tunnels, particularly the fact that there are only two Holland Tunnel tubes (and four lanes), as contrasted with the Lincoln Tunnel's three tubes and six lanes. Bus ridership from New Jersey to lower Manhattan is also adversely affected by the fact that there is no lower Manhattan express bus terminal. In contrast to Lincoln Tunnel buses, inbound buses using the Holland Tunnel must use seriously congested streets after they leave the tunnel. Outbound buses, of course, must also use congested city streets to reach the tunnel.

There are two one-quarter of a mile HOV lanes at the western approach to the Holland Tunnel Toll Plaza. The lanes, located at the far left of the toll plaza, are limited to 3+ carpools and buses during the heaviest two hours of the AM peak period (7-9 AM) and have specially designated HOV toll booths (Konecnick, 1989). During the entire morning peak period (7-10 AM), 132 buses and 3,991 bus passengers used the Holland Tunnel to reach Manhattan's CBD; 68 buses and 1,874 bus passengers used the tunnel during the peak hour (8 to 9 AM) (NYMTC, 1988, p.33).

George Washington Bridge HOV Lanes

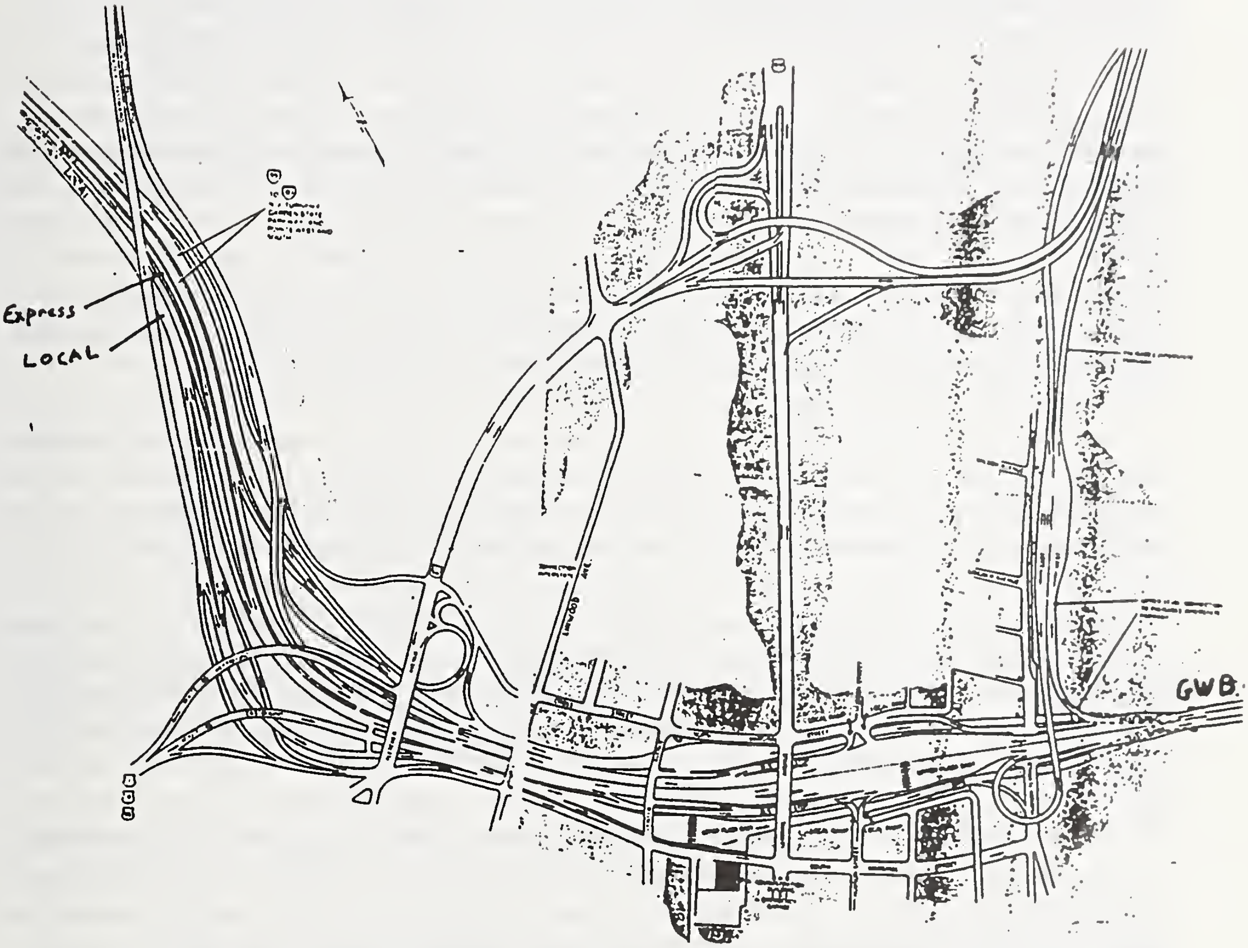
As Table 3-12 reveals, during the morning peak period, over 700 vehicles per day (mostly carpools) use two inbound 3+ HOV lanes at the approach to the George Washington Bridge. As Figure 3-6 indicates, the George Washington Bridge priority bus-carpool lanes originate at a point where two major interstate highways (I-95 and I-80) merge with three New Jersey state highways (1, 9 and 46) and extend to the George Washington Bridge Toll Plaza. There are three different approaches to the GWB priority lanes, on I-95/80 "Express", I-95/80 "Local", and U.S. Route 4 lanes. The longest approach is the I-95/80 Local, which begins 1.1 miles west of the main toll plaza.

Table 3–12. GWB HOV Lane Vehicle Volumes Typical AM Peak Period

	Number			Percentage		
Vehicle	Total	7–8 AM	8–9 AM	Total	7–8 AM	8–9 AM
Auto	582	399	183	82.6%	83.3%	81.0%
Bus	66	40	26	9.4%	8.4%	11.5%
Van	43	33	10	6.1%	6.9%	4.4%
Truck	14	7	7	2.0%	1.5%	3.1%
Total	705	479	226	100.0%	100.0%	100.0%

Source: Port Authority of NY & NJ, 1988.

Figure 3-6. HOV Lanes at the New Jersey Approach to the George Washington Bridge



The GWB HOV lanes operate only in the eastbound (toll) direction during the AM peak period (6:30-10 AM). There are no bus or carpool priority schemes during the PM peak period, either east or westbound. This reflects, as with the other bridge and tunnel access points to the Manhattan CBD, the fact that there is less peaking on the GWB during the PM period, when the volumes are dispersed over a longer period (Konecnik, 1988). As a result, PM congestion is less serious and there is less justification for the schemes during the afternoon and evening hours. Carpools normally use the toll booths located on the right hand side of the plaza, which are designated for their use and for use by buses and heavy-duty trucks. After they pass through the toll plaza, buses and carpools must merge with regular traffic.

Sixty-eight percent of the 705 AM peak period vehicles in the HOV lanes use them during the peak hour (7-8 AM). Only 66 buses use the HOV lane, with private automobiles accounting for over 80 percent of the vehicles using the HOV lanes. All of the trucks and approximately 25 percent of the autos using the HOV lane are violators.

The Queens Midtown Tunnel Approach

In October 1971, soon after the successful XBL demonstration project began operating, New York City DOT implemented a 2.5 mile contra-flow bus lane at the Queens (east) approach to the Queens Midtown Tunnel (QMT) Toll Plaza, i.e. I-495 West, the Long Island Expressway (LIE). The QMT contra-flow lane, which is available to inbound buses and taxis, uses the median eastbound lane during the morning peak period (6-10 AM). When the contra-flow lane is open, there are three inbound (west) LIE general traffic lanes, one bus/taxi contra-flow lane, and only two outbound (east) general traffic lanes. In addition, the two QMT tubes operate with three lanes of general traffic inbound and one outbound, as one of the tunnel's normal eastbound lanes is reversed.

Buses and taxis use a median barrier crossover to access the LIE contra-flow lane. There is no buffer and the contra-flow lane is designated by removable polyvinyl chloride traffic posts. Overhead signals notify motorists when the contra-flow lane is open.

The LIE contra-flow lane was used by an average of 377 buses and 14,000 bus passengers during the AM peak period in 1988; principally by public and private buses from eastern Long Island, Queens, and Kennedy and LaGuardia airports. Peak hour use (8-9 AM) averaged 189 buses and 7,932 persons (NYCDOT, counts October, 1988) (NYMTC, 1988, p.32-33).

Buses substantially increase the person carrying capacity of the QMT. Buses, which totaled only five percent of all vehicles, actually carry more persons through the QMT during the AM peak hour than automobiles do, 7,932 vs. 6,539 (NYMTC, 1988, p.32-33, 36). As Tables 3-4 and 3-5 indicate, buses carried 78 percent of the passenger volume of autos in three percent of the vehicles during the three hour peak period.

The New York City Department of Transportation, which manages and finances the LIE contra-flow lane operations, received technical assistance from the Port Authority in planning the operation and during the critical start-up period. The Port Authority staff, of course, had previously gained experience in contra-flow lane operations when carrying out the XBL demonstration project. As was true of the successful implementation of the XBL, inter-agency cooperation, in this case between the New York City DOT and the Triboro Bridge and Tunnel Authority (the owner and operator of the QMT), was and continues to be essential for effective operation of the scheme.

Conclusion

Bus and carpool priority schemes have made major contributions to improving AM peak period travel in the New York City Metropolitan area. Just under 200,000 commuters each morning (over 60 million annually) benefit from one or more of the inbound bus priority schemes connecting the rest of the city and suburban areas to the Manhattan CBD during the AM peak period. These schemes were designed as a complement to the region's extensive heavy rail and commuter rail systems which carry the bulk of trips. The region's bus and carpool priority lanes and other bus priority schemes are not physically impressive, but their performance and cost-effectiveness are very much so.

Many of the region's bus priority schemes are, in the words of one transit official, "quick and dirty, but quite effective." The quicker and dirtier schemes include the short queue jumpers at the entrances to the Holland Tunnel and George Washington Bridges. Even the area's more elaborate bus priority schemes, such as the XBL and the contra-flow lanes at the entrances of the Queens Midtown Tunnel and the Brooklyn Battery Tunnel, are quite simple when compared to the exclusive busways in Pittsburgh (Chapter 7) and Ottawa (Chapter 8) and Houston's transitways (Chapter 10).

New York's experience with bus and carpool priority schemes demonstrates that the attractiveness of these facilities to prospective transit and carpool users does not depend on elaborate stations or special buses. What is critical is that the schemes provide potential users with reliable service and significant savings in time and out-of-pocket costs. New York City may be an extreme case, because the costs of single occupant auto commuting are so high, but the NYC schemes nonetheless illustrate how relatively low-cost measures, including contra-flow lanes, short concurrent-flow lanes at bottleneck points, and priority processing at toll booths can significantly improve bus performance, reduce travel times, increase reliability, and increase bus ridership and carpooling.

Even with New York City's relatively long history of positive experience with the bus priority measures described in this chapter, local transit planners continue to encounter serious opposition to the implementation of more comprehensive schemes. Transit planners and policy makers have repeatedly expressed their frustration to us, particularly in following-up the obviously successful XBL with other exclusive bus facilities.* Even so, the active interest in the South and North Busway proposals in New Jersey, the recent commencement of services on the North Hudson Busway, and plans to extend the contra-flow lane at the approach to the Brooklyn-Battery Tunnel, indicate that the success of the XBL and other bus priority schemes in the region have persuaded many residents and policymakers that bus rapid transit can contribute to improving the region's commuter transportation. These successes hold out the promise that bus rapid transit will become more widely accepted.

New York City's experience with bus and HOV priority schemes provides many lessons. First, the 17-year history of the XBL illustrates that huge benefits can be obtained from relatively low cost bus rapid transit schemes. The XBL experience, for example, proves conclusively that a single, well designed bus priority lane can carry as many as 30,000 passengers an hour. Second, the New York City metropolitan area provides several other examples of simple and relatively easily implemented measures that have stimulated transit use and relieved traffic bottlenecks.

New York City's experience also provides valuable institutional and political lessons. The implementation and operation of the XBL highlights the importance of inter-agency cooperation -- between the New York, New Jersey, and New York City Departments of Transportation, the New York City Transit Authority, and the Port Authority. The metropolitan area's experience, and particularly with the XBL, also demonstrates that careful analysis of transportation alternatives can help raise awareness of the cost effectiveness of bus transit and can influence decision making. Finally the XBL experience illustrates the role of strong and

* One case in point was a proposed busway from Kennedy airport to the LIE contra-flow lane at the approach to the QMT which would have used abandoned Long Island Railroad right-of-way in the 1970's. This project met strong resistance by those who refused to accept the notion that buses could be used for rapid transit.

committed policy makers. Commissioner Kohl's action on the XBL demonstrated the importance of gaining commitment at the top for any transit proposal, particularly for the more novel projects.

Some people, mostly New Yorkers themselves, comment that if it works in New York City it can work anywhere. Even though bus priority schemes have succeeded brilliantly in New York City, we will resist the temptation of suggesting that they will work anywhere. Still, we are encouraged by the New York City experience, and hope other cities will carefully consider its relevance.

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Chapter 4. Measures to Encourage Transit Use and Carpooling in the Bay Area

Introduction

Like New York City, water barriers have had a major influence in shaping the Bay Area's urban development patterns and transportation infrastructure. If anything the impact is even greater as the San Francisco Bay is an even more formidable barrier than New York City's Hudson and East Rivers.

As Figure 4-1 shows, the City of San Francisco and its central business district (CBD) are located at the tip of a narrow peninsula. Marin and Sonoma Counties to the north are connected to San Francisco by a single bridge, the 1.7 mile long Golden Gate Bridge, which serves both U.S. Route 101 and State Route 1. The East Bay (Alameda and Contra Costa Counties) and Solano County to the North are similarly connected to San Francisco by a single bridge, the 8.4 mile long San Francisco-Oakland Bay Bridge (I-80), and by a 5.9 mile subway tunnel (shown by the dotted line in Figure 4-1). The tunnel was completed in 1974 to carry BART (Bay Area Rapid Transit) trains.

The mountainous character of the San Mateo peninsula south of San Francisco has limited intensive urban development to a fairly narrow strip along the bay. Highway access between San Mateo County and the San Francisco CBD is provided by U.S. Route 101, Interstate 280, and State Route 1, as well as numerous surface streets. The San Mateo/Hayward Bridge, State Route 92, connects San Mateo County with Alameda County. Santa Clara County and the City of San Jose, located to the south of San Mateo County, house very few San Francisco workers and are classified by the Census Bureau as being part of the San Jose MSA. The Dumbarton Bridge, State Route 84, links the southernmost part of Alameda County with Palo Alto in Santa Clara County.

Completion of the San Francisco-Bay Bridge in 1936 and of the Golden Gate Bridge in the following year were considered landmark engineering and construction achievements at the time. An indication of the cost and complexity of providing additional bay crossings is given by the fact that no serious schemes have been advanced for new tunnels or bridges for the last 17 years, although frequent proposals have been advanced to double deck the Golden Gate Bridge.*

The limited number of water crossings that connect San Francisco to Marin County and the East Bay have created both problems and opportunities for Bay Area transportation planners and policy makers. Since there has long been somewhat of a consensus that it would be impractical to build additional bridges across or tunnels under the bay, transport planners have

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* A new transbay bridge, the so-called Southern Crossing between Alameda in the East Bay and Hunter's Point in San Francisco, was a serious possibility until it was rejected by a voter referendum in 1972. However, work has been done on the bridges in the South Bay. For instance, Bay Bridge tolls were used to help finance the construction of the San Mateo-Hayward Bridge and the new Dumbarton Bridge.

Figure 4-1.

Major Highways Serving San Francisco Metro Area

had to become quite resourceful in increasing the effective capacity of the Golden Gate and Bay Bridges, particularly the latter.

This chapter reviews the Bay Area's experience with exclusive bus lanes, bus-carpool lanes, bus and carpool by-passes, and other preferential treatments at the approaches to the Bay and Golden Gate Bridges. The locations of these carpool lanes are shown in Figure 4-2. In addition, a brief discussion of the effects of the October 1989 earthquake on travel pattern is included. Before examining this experience, however, we briefly describe Bay Area travel patterns, emphasizing transbay commuting between the East Bay and Marin County and the San Francisco CBD.

Travel Patterns In the Bay Area

Journey-to-work statistics from the 1980 Census of Population and Housing are the best indicators of peak-period travel in the San Francisco-Oakland metropolitan area. Approximately 3.5 million daily work trips were made by 2.4 million commuters in the 9-county San Francisco Bay Area in 1980; 21 percent and 13 percent of these trips were to and from the City of San Francisco and the San Francisco CBD respectively.

As the data in Table 4-1 indicate, more than 284,000 individuals both worked and lived in the City-County of San Francisco;* this is more than half of the persons working in San Francisco in 1980. Nearly 79,000 persons, the second largest county-county flow, commuted from San Mateo County to work in San Francisco and nearly 51,000 persons commuted from Alameda County to work in San Francisco. The lower panel groups the nearly 220,000 inter-county commuters who work in San Francisco by East Bay (Alameda and Contra Costa Counties), South Bay (San Mateo and Santa Clara Counties) and North Bay (Marin and Sonoma Counties).** These data reveal that the most extensive commuting to San Francisco was from the East Bay, as nearly 90,000 East Bay residents a day used either the Bay Bridge or BART to reach jobs in San Francisco in 1980. Nearly as many persons commuted between the South Bay and San Francisco. The North Bay to San Francisco flow was less than half as large as the East Bay to San Francisco one.

Table 4-1 also provides transit mode-split data for work trips to the City-County of San Francisco and the CBD. These data indicate that 38.5 percent of all trips to work in San Francisco proper are by transit and that transit is used for nearly 50 percent of all worktrips to the CBD. These data indicate, moreover, that East Bay commuters are much more likely to use transit than either South Bay or North Bay commuters. For example, 47 percent of East Bay commuters making inter-county work trips to San Francisco use transit, as contrasted with only 28.5 percent of North Bay to San Francisco commuters. Even so, the fraction of North Bay commuters using transit exceeds that of South Bay commuters.

* Geographically the City of San Francisco and the County of San Francisco are one in the same.

** There is also a growing contingent of commuters to San Francisco who are not shown in Table 4-1. These individuals commute from Solano County and use the Bay Bridge after following I-80 through Richmond and Berkeley.

Figure 4-2.

San Francisco Bay Area HOV Lanes

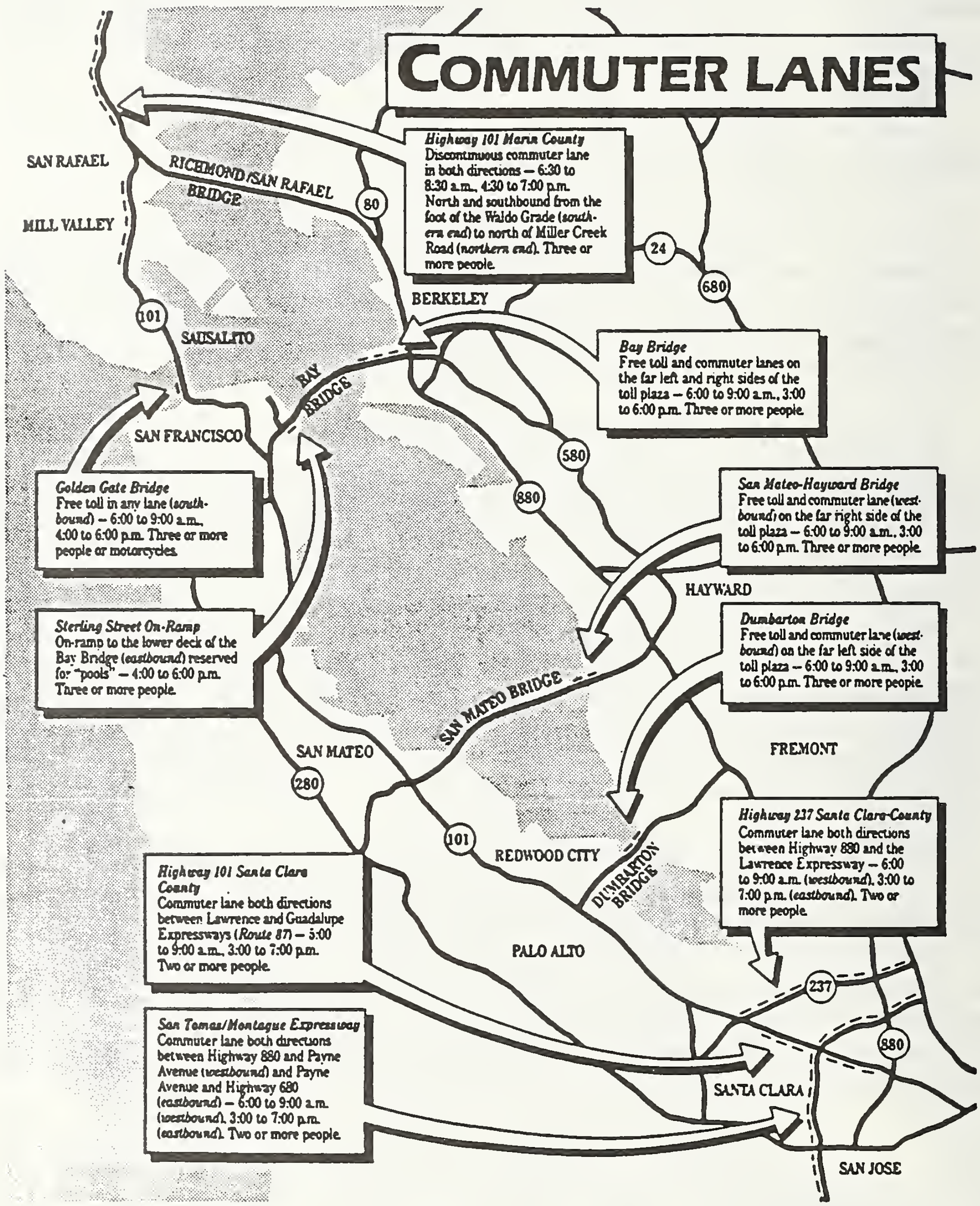


Table 4–1. Daily Commuting to the County/City of San Francisco and San Francisco CBD

County of Residence	All County Workplaces	Work Trips To San Francisco: All Modes CBD	All Modes City/Co.	Transit CBD	Transit City/Co.	Share of Transit CBD	Share of Transit City/Co.
San Francisco	330,848	165,423	284,297	91,080	120,361	55.1%	42.3%
Alameda	502,382	39,305	50,895	23,715	26,865	60.3%	52.8%
Contra Costa	295,533	31,024	38,236	13,871	15,052	44.7%	39.4%
Marin	113,715	26,412	37,662	8,943	10,327	33.9%	27.4%
Sonoma	124,515	2,870	6,489	1,821	2,246	63.4%	34.6%
San Mateo	301,016	46,420	78,706	13,911	16,120	30.0%	20.5%
Santa Clara	643,416	5,836	7,438	2,935	3,172	50.3%	42.6%
Totals	2,311,425	317,290	503,723	156,276	194,143	49.3%	38.5%
East Bay	797,915	70,329	89,131	37,586	41,917	53.4%	47.0%
South Bay	944,432	52,256	86,144	16,846	19,292	32.2%	22.4%
North Bay	238,230	29,282	44,151	10,764	12,573	36.8%	28.5%
Totals	1,980,577	151,867	219,426	65,196	73,782	42.9%	33.6%

Source: Journey To Work, U.S. Census, 1980.

The relatively low share of transit use by South Bay to San Francisco commuters reflects the absence of water barriers and toll facilities, the greater highway capacities provided by US 101, I-280, and connecting city streets on the Peninsula to San Francisco, and the relative unavailability of high performance transit between the South Bay and the San Francisco CBD.* This contrasts sharply with the situation in the East Bay and to a lesser extent with the North Bay where all commuters must cross a water barrier.

Travel between the East Bay and San Francisco

As Figure 4-1 shows, the 8.4 mile long Bay Bridge (Highway I-80), links San Francisco to the East Bay and connects to three major East Bay freeways, I-80, I-880 (the Nimitz Freeway) and I-580. The bridge has two levels with one-way traffic on each deck: the upper deck has five westbound traffic lanes, while the lower deck has five eastbound traffic lanes. The toll plaza is located at the east approach to the bridge. Tolls are collected only on trips into San Francisco (westbound) and are currently $1 for low occupancy vehicles (LOVs); buses and carpools are exempted from tolls during peak hours.

The roadway at the western end of the Bay Bridge connects a series of exit-entrance ramps to local streets in the San Francisco CBD, to an exclusive bus ramp to the Transbay Bus Terminal, and to US-101 South, a freeway that connects areas south of San Francisco (South

* The California Department of Transportation (Caltrans) offers commuter rail service from San Jose to San Francisco, but the San Francisco depot is located at a considerable distance from the CBD.

San Francisco, San Mateo, and the San Francisco International Airport) to the CBD and the Bay Bridge.

Daylight hour (6 AM-6 PM) counts of person trips between the East Bay and San Francisco shown in Table 4-2, provide a more comprehensive measure of tripmaking between the East Bay and San Francisco. These data indicate that during daylight hours in April 1987, over 190,000 persons per day made trips between the East Bay and San Francisco by either the Bay Bridge or BART. Slightly more than 150,000 person trips per day were made in the opposite direction during the same 6 AM-6 PM period.

AM peak period person trips by all modes in 1987 made up approximately 40 percent of the trips from the East Bay to San Francisco (westbound). As the data in Table 4-3 reveal, nearly two-thirds of these trips used the Bay Bridge and one-third used BART. Transit accounted for approximately 43 percent of all westbound AM peak period trips between the East Bay and San Francisco: 34 percent of total trips were on BART and nine percent were on buses, principally Alameda-Contra Costa County Transit (AC Transit) express buses. Transit's share of eastbound trips during the evening peak period is even larger, 47 percent (35 percent on BART and 12 percent on AC Transit). These data also reveal that the fraction of person trips by carpool is much higher in the AM than in the PM peak period, 29 percent versus 13 percent of total peak period person trips, because of the casual carpooling that will be discussed later.

About the same number of persons commute by carpool as by LOVs during the AM peak period, but carpools use only about one-third as many vehicles as do LOVs. As a result, carpools and vanpools comprise 25 percent of all vehicles, but serve 44 percent of all passenger trips using the Bay Bridge during the AM peak period. During the AM peak period buses carry 14 percent of all person trips in one percent of the vehicles using the Bay Bridge.

Evening peak period mode splits for the Bay Bridge are very different from morning ones. During the PM peak period, carpools account for only 20 percent of all person trips on the Bay Bridge as compared to over 40 percent during the AM peak period. The markedly higher carpool use in the morning than in the evening is due to more extensive schemes benefiting carpooling in the morning and the greater ease of organizing casual carpools during the morning peak.* As a result of these conditions, auto occupancy rates are 30 percent lower during the evening peak period than during the morning peak period. These and similar data suggest that a significant amount of carpooling on the Bay Bridge has been induced by priority measures during the morning peak period. We now provide a brief description of the Bay Bridge HOV scheme and discuss the ways in which it has changed over time.

Streetcars on the Bay Bridge

Between the Bay Bridge's opening for traffic in 1936 and 1962, its lower deck had streetcar tracks for Key System trains, streetcars or trams (the so-called green cars), running be

* The benefits to carpooling are greater in the morning westbound commute: toll bypass lanes and free tolls for 3+ occupant vehicles operate in the westbound (morning peak commute) direction. Morning carpool trips are more convenient as trips during the morning are made from many origins to a single destination (the CBD) at a single time, while those in the afternoon are made from a single origin (the CBD) to many destinations with varied departure times. The problems of organizing informal evening carpools are thus much greater than those of organizing morning ones.

Table 4–2. Numbers and Shares of Daylight Hour (6 AM – 6 PM) Person Trips Between the East Bay and San Francisco by Mode, April 1987

Mode	Person Trips	Percent of Total
Westbound		
In Passenger Vehicles	139,432	73.1%
Bus	10,662	5.6%
BART	40,776	21.4%
Total	190,870	100.0%
Eastbound		
In Passenger Vehicles	102,057	67.9%
Bus	12,872	8.6%
BART	35,365	23.5%
Total	150,294	100.0%
Total Both Directions		
In Passenger Vehicles	241,489	70.8%
Bus	23,534	6.9%
BART	76,141	22.3%
All	341,164	100.0%

Source: Metropolitan Transportation Commission, April, 1987.

Table 4–3. Transbay and Bay Bridge Peak Period Person and Vehicle Trips by Direction in 1987

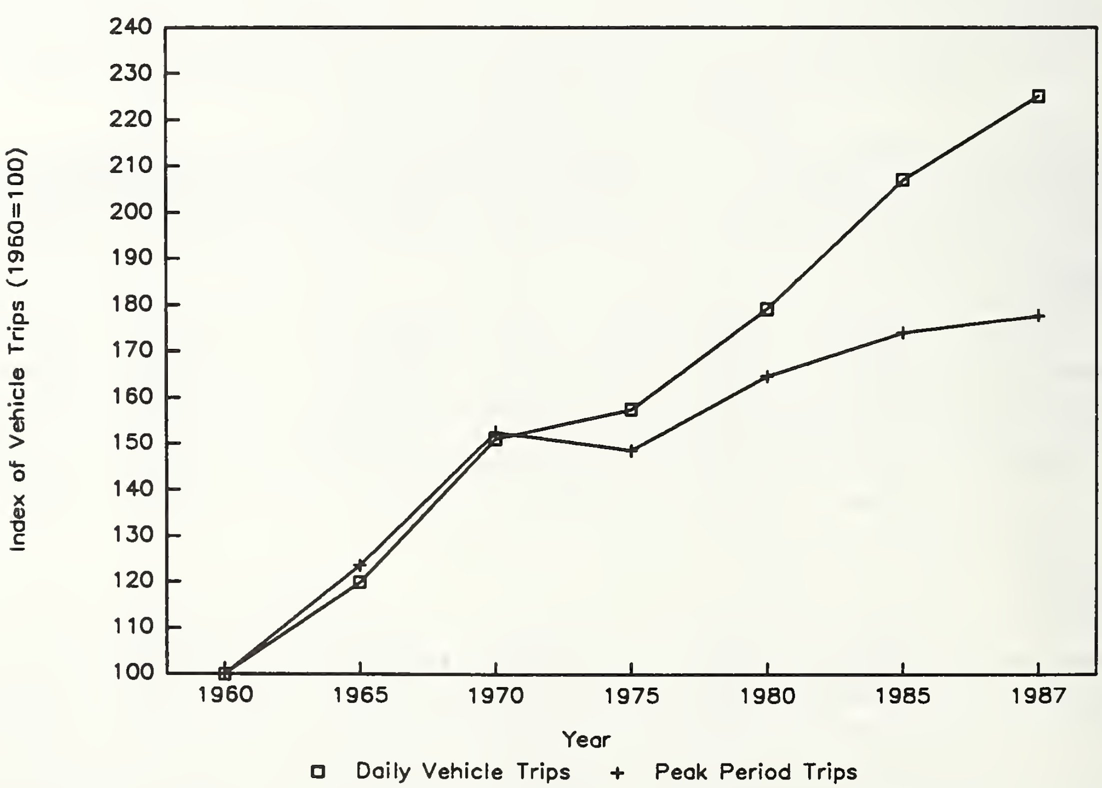
Direction	Number		Transbay Modal Shares		Bay Bridge Modal Shares	
and Mode	Vehicles	Persons	Vehicles	Persons	Vehicles	Persons
Westbound						
(AM Peak)						
LOVs	18,311	21,390	73.8%	28.1%	73.8%	42.3%
Carpools	6,163	22,056	24.8%	28.9%	24.8%	43.7%
Buses	332	7,070	1.3%	9.3%	1.3%	14.0%
BART	N/A	25,700	N/A	33.7%	N/A	N/A
Total	24,806	76,216	100.0%	100.0%	100.0%	100.0%
Eastbound						
(PM Peak)						
LOVs	23,568	28,667	91.2%	40.1%	91.2%	61.8%
Carpools	1,962	9,064	7.6%	12.7%	7.6%	19.5%
Buses	318	8,687	1.2%	12.2%	1.2%	18.7%
BART	N/A	25,067	N/A	35.1%	N/A	N/A
Total	25,848	71,485	100.0%	100.0%	100.0%	100.0%

Source: MTC Traffic Counts, 1987.

tween the East Bay and downtown San Francisco. In 1960, the Key System trains carried approximately 28,000 passengers per day between the East Bay and San Francisco (both eastbound and westbound) and Greyhound, the principal trans-bay bus operator, carried an additional 5,000 passengers per day (MTC, 1960). During this period, the bottom deck also provided three lanes of roadway for the use of buses and trucks, configured 1-1-1, i.e. one eastbound, one westbound and one reversible; no buses or trucks were allowed to use the upper deck and no cars were allowed to use the bottom deck. The upper deck was used by both eastbound and westbound auto traffic.

In 1962, well before transbay BART service began in 1974, the Key System tracks were removed from the lower deck and the roadway was rebuilt to provide five eastbound general traffic lanes for the use of cars, trucks, and buses. At the same time, all five lanes on the upper deck were allocated to westbound autos, buses, and trucks. As Figure 4-3 indicates, removing the streetcar tracks and reconfiguring the lower deck significantly increased the bridge's effective vehicle capacity. As the indices of westbound Bay Bridge vehicle trips for selected years between 1960 and 1987 indicate, removing the Key System tracks from the lower deck permitted a rapid growth in both daily and peak period vehicle use of the bridge until 1970 when the capacity constraint became binding again, though at a higher level.

Figure 4-3. Index (1960 Levels = 100) of Westbound Daily and AM Peak Period Trips on the Bay Bridge For Selected Years, 1960-1987



Bay Bridge daily and peak period vehicle volumes increased by approximately 50 percent between 1960 and 1970. In the next 18 years, i.e. 1970 to 1987, daily westbound vehicle trips grew by an additional 49 percent, but peak period trips, constrained by bridge capacity, grew by only 17 percent. The modest 17 percent increase in peak period use during 1970-87 was made possible by a series of priority and traffic engineering schemes, discussed in subsequent sections, and is a tribute to the ingenuity of the California Department of Transportation's (Caltrans) engineers.

The temporary slowdown in the growth of daily vehicle trips and temporary decline in the level of peak period vehicle trips between 1970 and 1975 are undoubtedly explained by the Introduction of BART transbay service in 1974. As the data in Table 4-4 reveal, BART carried nearly 13,000 westbound AM peak period passengers in 1975 and total AM peak period transbay transit ridership (BART plus AC Transit) increased from about 19,300 in 1970 to about 27,100 in 1975.

At the same time the streetcars were removed from the Bay Bridge, the Key System terminal in San Francisco was converted to bus use and the ramps that had carried Key System trains between the bridge and the terminal were converted to exclusive bus ramps. These bus-only ramps (which remain in operation to this day) allow buses using the bridge to reach the downtown San Francisco bus terminal without using congested city streets. The Transbay Bus Terminal, which is located at the southern edge of the CBD and is within easy walking distance of San Francisco's financial district, serves as a central transfer point for AC Transit transbay, San Francisco MUNI, Golden Gate Transit, SamTrans (San Mateo County), and Amtrak access bus services.

History of Bay Bridge Bus/Carpool Priority Measures

California, with its high rates of auto ownership, rapid population growth and legitimate and well articulated concerns about congestion and the environment, has been something of a

Table 4–4. Total Daily and Peak Period (6–9 AM) Westbound Transit Person Trips by Bus and Rail for Selected Years, 1960–1987

Persons	1960	1965	1970	1975	1980	1985	1987
Total Daily							
Bus Passengers	16,371	20,665	27,061	19,262	24,220	13,977	9,524
BART	0	0	0	25,899	34,085	52,395	45,117
Total	16,371	20,665	27,061	45,161	58,305	66,372	54,641
Peak Period							
Bus Passengers	9,832	14,317	19,344	14,038	17,757	10,809	7,070
BART	0	0	0	13,073	18,769	30,324	25,715
Total	9,832	14,317	19,344	27,111	36,526	41,133	32,785

Note: 1960 Bus Passengers includes Key System Transbay Passengers.
Source: University of California, ITTE, Traffic Survey Series, Metropolitan Transportation Commission.

leader in implementing bus and carpool priority measures. In 1970, the California State Senate instructed Caltrans to study experimental bus and carpool lanes, and in the same year the California State Legislature amended the California Streets and Highways Code to allow Caltrans to construct new lanes or to use existing lanes on state highways for HOVs. The amendments authorized Caltrans to sign and maintain preferential lanes, install traffic control devices as needed, and designate specific hours and occupancy levels for lane use.

In the late 1960's, Bay Area policymakers began to study the possibilities of implementing various bus and carpool priority measures that would encourage greater bus and carpool use without "unduly penalizing" other highway users. Their first efforts, not surprisingly, focused on the Bay Bridge and the first phase of the Bay Bridge bus/carpool priority scheme, a half-mile exclusive bus lane, was implemented in April 1970. During the AM peak, buses were provided with an exclusive lane at the approach to the toll plaza and were allowed to bypass the toll booths before merging with regular traffic at the foot of the bridge. This simple scheme, which permitted buses to bypass the queues at the toll plaza, was highly effective.

The "1970 exclusive bus lane" at the approach to the Bay Bridge toll plaza was created by "taking away" one of the middle general traffic lanes.* There were immediate complaints. When the exclusive bus lane was first implemented, over 500 buses used it during the three hour AM peak period (6-9 AM). Nevertheless, the lane appeared to be underutilized, especially when compared to the heavily congested general traffic lanes parallel to it.

Because of growing public opposition to the lane's "underutilization" and, perhaps more importantly, because of Caltrans's commitment to maximizing vehicular flow, the exclusive bus lane was converted to a bus/carpool facility. Starting in December 1971, three or more persons per vehicle (3+) car and vanpools were allowed to use the formerly exclusive bus lane. A few months later (March 1972), Caltrans implemented two additional priority lanes (an additional HOV lane and an exclusive bus lane) as part of a larger highway widening project. Center Lanes 8 and 9 (of the 17 lane Toll Plaza) were designated HOV lanes and Lane 10 was made an exclusive bus lane.

The length of the priority lanes at the approach to the Bay Bridge toll plaza has varied over time. The original 1.5 mile length of the HOV lanes was reduced on several occasions between 1971 and 1975 until they reached their present length of one-third of a mile. These modifications were the result of Caltrans ongoing efforts to improve traffic flow in the general traffic lanes.

The HOV lanes are ordinary traffic lanes, designated for buses and carpools and identified by extensive signage and removable plastic stanchions. Because the lanes initially operated only during the morning peak period, the stanchions had to be removed and replaced each morning. Weekday hours for lane operation were subsequently lengthened to 6 AM-6 PM to accommodate increased off-peak demand; then in July 1977 the hours of HOV operation were restored to their original times (6-9 AM and 3-6 PM). The current hours (January 1989) of HOV operations are 5-10 AM and 3-6 PM.

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* This was one of the first, if not the finest instance in North America of a general purpose highway lane being converted to exclusive bus use.

For a six month period following December 1971, carpools using the HOV lanes were exempted from tolls. Then starting in May 1972, carpools were required to show a carpool identification card that could be purchased for one dollar a month, or pay the fifty cent regular toll. According to Bay Bridge authorities, toll charges for carpools were reintroduced, albeit at levels well below those for other vehicles, because additional revenues were needed to retire Bay Bridge debt. Carpools were once again exempted from tolls in March 1975 and the policy continues to the present.

In September 1972, the California Department of Public Works (DPW) installed traffic lights about 1,000 feet downstream, i.e. towards the bridge, from the toll plaza to control vehicle access onto the bridge. As vehicular volumes approach capacity, the wait times, i.e. red phases, are automatically increased to meter the number of non-priority vehicles using the bridge, thereby preventing congestion from growing too severe on the bridge deck. The metering system is designed to feed traffic to the bridge at rates that maximize the bridge's vehicular capacity. While this policy provides significant travel time advantages for buses and carpools, even larger time savings would result from a policy that traded-off some vehicular capacity for higher speeds. The metering system uses sensors that measure vehicle volumes on the bridge and overhead message signs west of the toll plaza inform bridge users of any extended delays.

DPW used "reduction of existing delay to people using the bridge each weekday morning between 6 and 9 AM" as its criteria in evaluating the 3-lane priority scheme (California DPW, 1973). When the scheme was first introduced in 1972, the region's transport planners thought that the time savings provided by bus and carpool use would divert enough motorists to transit and carpools to result in a reduction in peak hour vehicle demand. They hoped, moreover, that these mode shifts would reduce congestion and delays for both priority and non-priority bridge users.

As MTC data indicate, however, the implementation of the priority scheme did not result in a decline in the number of vehicles using the Bay Bridge during peak periods. At the end of the scheme's first full year, i.e. 1973, approximately 23,000 vehicles used the bridge for westbound trips during the 3-hour AM peak period, a number that is almost identical to the number using the bridge before the priority measures were introduced. The measures did, however, lead to increases in the number of person trips and vehicle occupancy; both increased by eight percent and the bridge was able to accommodate an additional 2,300 persons during the AM peak period (MTC, 1972 and 73).

Introduction of the three lane priority scheme in 1972 increased the number of carpools using the bridge during the AM peak period. The number of carpools rose by 91 percent in one year, from 1,100 to 2,100 (MTC, 1972 and 73). Buses and carpools experienced many fewer delays than other vehicles and users of the priority lanes saved five minutes compared to users of the general traffic lanes.

The exact effects of the bus-carpool lanes on carpooling and bus ridership, however, are hard to isolate because carpool use was affected by several factors other than the existence of a carpool lane. For example, when carpool tolls were reintroduced in May 1972, albeit at levels well below those for single-occupant vehicles, the number of carpools leveled off and even decreased slightly. An AC Transit strike in July 1974 caused a sharp increase in the number of carpools to 4,400; and when BART began service between the East Bay and San Francisco in

October 1974, the number of AM peak period carpools fell sharply to 1,800. In April 1975, carpools were once again exempted from all tolls and the number of carpools rose to over 2,000; and a second AC Transit strike in November 1977 caused an abrupt increase in the number of carpools to 3,600 (Caltrans, 1978, p. 23).

While the trend data provide support for the view that the travel time and toll reductions provided by the priority schemes increased carpooling during the 1970's, their effect on transit ridership is less clear-cut. The limited available evidence suggests that carpooling incentives had only a modest effect on East Bay to San Francisco bus ridership. At the end of the experiment's first year, i.e. 1973, DPW analysts estimated that less than two percent of peak period bus riders, i.e. 200 of 14,000, had switched from buses to carpools as a result of the carpooling incentives (California DPW, 1982, p.19). This is in sharp contrast with BART's effect on AC Transit transbay ridership.

Introduction of BART transbay services in 1974 had a large negative impact on AC Transit express bus ridership between the East Bay and San Francisco. While we do not have detailed before and after data on bus ridership, BART's impact is evident from AC Transit's decision to reduce its transbay bus trips by 20 percent (from 500 to 440 buses per day) after the introduction of BART service to San Francisco. As Table 4-4 reveals, peak period transbay bus ridership fell from more than 19,000 in 1970 to approximately 14,000 in 1975; BART peak period ridership exceeded 13,000 in 1975. These data also indicate that both peak period bus and BART ridership grew between 1975 and 1980. Transbay bus ridership, however, declined after 1980 and by 1987 it was only 40 percent of the level it had been eight years earlier.

The California Highway Patrol (CHP) has the somewhat unenviable responsibility of policing Bay Bridge bus and carpool lanes. Enforcement of the 1972 scheme was greatly complicated by the fact that the HOV lanes were located in the middle of the toll plaza. Because of the resulting enforcement problems and other factors, Caltrans (1978) estimated that 30 percent of the cars using the lanes during the first two years of the experiment were violators, i.e. they had fewer than three occupants. Somewhat surprisingly, DPW analysts concluded that these violations increased total benefits, since they reduced vehicular volumes and travel times in the non-priority lanes without significantly increasing travel times for buses and carpools in the HOV lanes.

In the absence of the high violation rates, the Bay Bridge HOV lanes would have been used at well-below their capacity and users of general traffic lanes would have experienced increased travel times (California DPW, 1973, p. 4). The Bay Bridge experience is by no means unique. As we discuss further in Chapter 10 on Houston's transitways and in Chapter 15, the cost-effectiveness of bus-HOV facilities depends critically on their utilization. In many cases where buses and 4+ or 3+ carpools use only a fraction of an HOV lane's capacity, total benefits can be increased by policies that increase vehicle use. At the same time care must be exercised to insure that greater carpool use does not reduce speeds and travel time savings for buses and other high occupancy vehicles.

The initial decision to locate the Bay Bridge HOV lanes in the middle of the toll plaza caused problems other than enforcement. The centrally located HOV lanes had a "damming" effect that often lead to unequal volumes in the general traffic lanes on either side. General traffic lanes on one side of the HOV lanes would often experience serious congestion and long

queues at the same time that lanes on the opposite side of the HOV lanes were underutilized. Buses and carpools also frequently experienced difficulty in crossing heavily congested general traffic lanes to reach the centrally located HOV lanes. As a result of continuing operational problems with the center HOV lanes and a steady growth in carpool demand, Caltrans implemented a somewhat different HOV lane arrangement in 1980.

The Current Bay Bridge Scheme

The Bay Bridge priority scheme operates in the westbound direction during both the AM and PM peak periods.* Westbound traffic using the Bay Bridge enters the east approach to the bridge from a three lane ramp off of I-80, a three lane ramp off of I-580, and a two lane ramp off of I-880. The eight lanes become six lanes at the approach to the toll plaza and then widen to 19 lanes at the toll plaza itself. When vehicles leave the toll gates, they merge to 15 lanes and, if necessary, are held at metering lights located one-quarter mile west of the toll plaza. From the metering lights, vehicles merge to one of the bridge's five westbound lanes. The meters feed traffic to the bridge deck in such a way that delays are minimized.**

The current (May 1988) priority scheme has two westbound HOV lanes and a single westbound bus-only lane. The three priority lanes, located on both sides of the westbound roadway at the Bay Bridge approach and toll plaza, operate during both the morning (5-10 AM) and evening (3-6 PM) peak periods. The furthest right-hand lane is an exclusive bus lane and the one adjacent to it is a 3+ carpool and vanpool lane. The furthest left-hand lane is also an HOV lane, which may be used by either 3+ car and vanpools or buses. Since all express bus routes that currently cross the Bay Bridge use the two right-hand side lanes, the HOV lane on the left hand side of the bridge approach is for all practical purposes a 3+ carpool and vanpool lane.***

All three bus/carpool lanes are ordinary highway lanes that have simply been designated for 3+ carpool and bus use during peak periods. Their current length is approximately .62 of a mile, .38 mile before and .25 mile after the toll booths to the metering lights. East of the toll plaza, the HOV lanes are marked by solid white lines, diamonds and extensive signage; west of the toll plaza, they are separated by permanent plastic stanchions. During peak periods, buses, carpools, and vanpools are exempted from the $1.00 (1989 dollars) toll and are given priority at the meters.**** Buses and carpools seldom need to stop at the metering lights, the principal exceptions occur when a serious accident causes bridge traffic to back-up.

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* The description that follows refers to the situation as it was before the October 1989 earthquake caused a section of I-880 to collapse.

** In December 1988, changeable message signs were added in front of the toll plaza and a new laser sensor was installed to improve vehicle detection on the bridge and to better control conditions on the bridge. As noted previously, the message signs located west of the toll plaza were installed when metering began in 1972.

*** 80 percent of AC Transit transbay buses enter the right-hand side lanes via Grand Ave. in Oakland from points in Oakland and southeastern Alameda County. The other 20 percent reach the lanes via I-80, primarily from points in Berkeley, Albany, and western Contra Costa County.

**** All dollar amounts are in constant 1989 dollars, unless otherwise noted. Current year construction cost amounts are converted to constant 1989 dollars using the ENR Construction Cost Index, operating and other costs are adjusted using the GNP Implicit Price Deflator.

The Bay Bridge bus-only and bus/carpool lanes provide significant time savings and greater reliability. The most recent estimates (May 1988) indicate that the HOV facilities save buses and carpools an average of 20 minutes during the AM peak period (MTC, 1988). There are presently no eastbound priority schemes, but some are being considered as part of a new corridor plan.

Bus Use of the Bay Bridge

Seventeen AC Transit express bus routes currently (May 1988) use the Bay Bridge and benefit from the priority measures described above. These routes primarily serve commuters from the East Bay cities in western Contra Costa County and eastern Alameda County. Of 865 scheduled daily AC Transit bus trips that use the Bay Bridge, over 63 percent (540) are made during peak periods (AC Transit, 1988). In 1987, these AC Transit buses carried close to 16,000 peak period east and westbound person trips (MTC, 1987d).

As noted previously, PM peak period bus ridership is about 23 percent greater than AM peak period ridership. More than 8,600 Bay Bridge trips are made by bus during the three hour evening peak period; this compares to about 7,000 during the morning peak period. During the PM peak hour, buses carry over 5,200 person trips on the bridge as contrasted with about 4,000 in the AM peak hour.

Significant numbers of East Bay commuters use carpools to commute to work in the morning and take the bus or BART home in the evening. During the AM peak period, many drivers of single occupancy private automobiles pick up riders at informally designated locations (frequently at or near express bus stops or at entrances to freeways leading to the Bay Bridge) in order to qualify as carpools. Passengers and drivers are mutual beneficiaries of this system: they both save an average of 20 minutes in their trip to San Francisco; the drivers avoid paying the $1.00 toll; and the riders are saved the $1.00 bus or the $1.75 or more BART fare (all dollar amounts are in 1989 dollars).

Casual carpooling has been a source of considerable concern to transportation planners and policy-makers in the Bay Area. AC Transit in particular, has been deeply disturbed by the practice and its impact on bus ridership. The Bay Bridge exclusive bus and HOV lanes are meant to reduce congestion and vehicular use of the bridge by increasing average vehicle occupancy and transit use. The diversion of morning only casual carpoolers from transit to carpools may undermine these objectives by reducing bus ridership, by increasing AC Transit losses, and by encouraging the continued use of low occupancy vehicles by permitting them to disguise themselves in the morning as carpools.*

AC Transit officials contend that Bay Bridge carpooling incentives have diverted large numbers of morning bus riders from transit. In a recent survey, 40 percent of the drivers of carpools indicated that they would use transit if carpools were not given priority treatment (AC Tran-

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* Whether Bay Area bus operators are hurt or helped by casual carpooling depends on whether they have to add buses to serve the PM peak or whether they can accommodate the larger PM loads without increasing the number of peak vehicles. It is even more difficult to determine the fraction of the drivers who would join "legitimate" carpools or switch to transit if the practice could be abolished.

sit, 1987). This evidence suggests that the particular set of Bay Bridge carpooling incentives now in force, by reducing the cost of commuting for many drivers, may have reduced transit use and may have thereby added to the number of vehicles using the bridge. It also likely that casual carpooling has also decreased transit use by lowering the time and organization costs of carpooling. These issues are very complex and we lack the information to provide a definitive assessment. Even so, it appears that the combination of carpooling incentives and casual carpooling have reduced transit use somewhat.

Over the past several years, AC Transit has experienced large ridership declines and growing operating deficits (operating expenses minus fare revenue). As the data in Table 4-4 show, AM peak period transbay bus ridership has declined from slightly over 27,000 in 1970 to approximately 24,000 in 1980, to just under 14,000 in 1985, and finally to about 9,500 in 1987. Declines in transbay express bus patronage account for a significant part of the decline in AC Transit daily ridership, which fell from 254,000 in 1986 to 222,500 in 1987 and may have contributed to the steep rise in AC Transit's operating deficit, which reached $86 million (1989 dollars) in 1987 (MTC, 1987).

To a considerable extent, AC Transit's deteriorating operating experience reflects the worsening performance of the East Bay to San Francisco express bus routes, the same routes that have been most adversely affected by casual carpooling. AC Transit (1987a) estimates that 2,000-3,000 "transit users" join casual carpools each weekday and that it loses approximately $1.1 million (1989 dollars) in annual revenue as a result of the practice. While these ridership loses are significant, they account for at most 1.3 percent of AC Transit's 1987 operating deficit.

The economic performances of the 17 transbay express bus routes in fiscal year 1987 were substantially worse than those of AC Transit's other routes. Per passenger subsidies on express routes were more than twice the system-wide average of $1.24 (1989 dollars). These routes, moreover, averaged 17 passengers per service hour as compared to a system average of 32. Finally, the express bus routes carried an average of 0.86 passengers per mile, compared to a system wide average of 2.2 (AC Transit, 1987a, p. vi-20-25).*

It is doubtful that casual carpooling was the only, or even the principal, explanation for the poor performance of AC Transit express routes. Other factors, including competition from BART and AC Transit's failure to adjust routes and schedules to reflect changes in demand and competition from other modes, are at least as important. The nearly empty back-hauls and extreme peaking that characterize express bus routes nearly everywhere, however, are the principal explanations for the low productivity of these routes in comparison to AC Transit routes in general.

It is also likely that the poor performance of transbay express routes is explained in part by AC Transit's failure to adjust the transbay express routes to changes in demand. While we have not been able to complete the careful route by route assessment of AC Transit operations that would be required for a definitive answer, it appears AC Transit may have failed to adjust its schedules to the growth in casual carpooling and to declining transbay patronage. AC Transit actually operates more transbay bus trips during the AM peak period than during the PM, 333 to

* These averages vary considerably among transbay express bus routes; the subsidy per passenger in 1989 dollars varied from $0.24 to $5.62 and passengers per service hour ranged from less than 11 to 49.

318. As a result of greater service provision in the AM peak and the absence of significant carpooling in the PM peak period, average bus occupancy is 21 persons during the AM peak as compared to 27 during the PM peak. The higher PM load factors for express routes are still low, however, particularly when it is recognized that AC transit uses articulated buses for many of these routes.

AC Transit has tried to combat casual carpooling by changing its fare structure. In 1987, AC Transit began charging $1.08 for westbound and $2.17 for eastbound trips instead of its previous practice of a uniform $1.63 fee for trips in both directions (all amounts are in 1989 dollars). These changes were followed by a two percent increase in ridership and an estimated eight percent increase in revenues.* AC Transit's efforts to use differentiated fares to combat casual carpooling were undermined somewhat by BART's refusal to make a similar change in its fare structure. As a result, some casual carpoolers, who formerly made bus trips in the evening, now avoid AC Transit's higher eastbound fare by using BART for their return trips to the East Bay.

The October 1989 Earthquake

On October 17, 1989 the San Francisco Bay Area was struck by an earthquake measuring 7.1 on the Richter scale. The earthquake caused numerous deaths and extensive property damage throughout the region. Major damage was done to the Bay Bridge and to some highways leading to and from the bridge: the bridge itself was closed to all vehicle traffic until mid-November; the portion of I-880 (the Nimitz Freeway) bordering Cypress Street in West Oakland collapsed and has since been demolished; and the Embarcadero Freeway in San Francisco was still closed as of January 1990. Currently, all San Francisco and I-80 bound traffic on the Nimitz must detour along I-980 and I-580 to reach both the approach to the Bay Bridge and I-80. The disaster had a severe impact on commuter behavior during the period while the Bay Bridge was closed.

While the bridge was closed passenger volumes on both BART and the other bridges across the bay to San Francisco and the Peninsula increased dramatically. Preliminary figures from the Metropolitan Transit Commission (MTC) indicate that AM peak period (5-10 AM) transbay ridership on BART may have increased by as much as 115 percent prior to reopening the bridge.** AM peak period vehicle volumes on the Golden Gate Bridge increased by over 15 percent, and vehicle volumes on the three other East Bay to West Bay bridges apparently rose by 35 percent. In an effort to ease congestion on BART, ferry service was introduced between the East Bay and San Francisco. However, the impact on commuter flows was small; total ferry passenger volumes were less than 10 percent of the BART increase alone. Commuter traffic began to use the bridge again on November 20, 1989.

Commuter behavior after the reopening of the Bay Bridge continues to differ from pre-earthquake patterns. The principal explanation for these changes is undoubtedly the

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* The eight percent estimate assumes that the number of riders using AC Transit in the PM peak period remained unchanged and that the entire two percent increase occurred in the AM peak period. This may overstate revenue growth somewhat because of the diversion of some AC Transit users to BART during the PM peak period.

** All the pre and post earthquake figures discussed here are estimates. They are based on preliminary data supplied by MTC and have not yet been fully reviewed by MTC staff.

added delays to San Francisco bound commuters using I-580 caused by the addition of traffic that formerly used the Cypress portion of I-880, which was destroyed by the earthquake. BART AM peak period transbay ridership was approximately 14 percent higher than the pre-quake levels three weeks after the Bay Bridge reopened. BART ridership declined steadily over this three week period, however. Post-quake data on Bay Bridge bus and carpool passenger volumes were unavailable when this chapter was prepared and thus no precise analysis could be made of the quake's impact on the use of the recently reopened Bay Bridge. Given that BART ridership was 14 percent above pre-quake levels, however, it is probable that Bay Bridge passenger volumes had not reached pre-quake levels. Traffic volumes on the other transbay bridges appear to have returned to the pre-earthquake levels.

Plans for East Bay HOV Schemes

While priority measures at the approach to the Bay Bridge have reduced travel times and increased average vehicle occupancy during peak periods, buses and carpools have experienced increased delays in other parts of the corridor. As Figure 4-3 indicates, the number of vehicles using the Bay Bridge has grown steadily since 1960. Traffic growth has been even more rapid in other parts of the corridor and the worst congestion increasingly occurs at points well removed from existing Bay Bridge priority schemes and at times (or in the direction) when the priority schemes are not in effect.

The extent and duration of congestion has grown dramatically in the past 15 years, particularly along I-80. Congestion now exists throughout the day and in both directions. During the AM peak period, serious traffic congestion consistently extends from points north of Pinole down to the Bay Bridge (see Figure 4-1). Estimates published by the MTC (1987, p. 3) indicate that peak hour travel times on I-80 from the Carquinez Bridge to the Bay Bridge have increased from an average of 31 minutes in 1980 to 44 minutes in 1985.

During the evening peak period, eastbound traffic, with increasing regularity, backs up at the highways leading from the Bay Bridge.* There are presently five lanes in each direction at the point where I-80 joins I-580 and I-880. At the Ashby Avenue interchange in Berkeley, however, I-80 narrows to four lanes; this produces a bottleneck that increasingly creates queues that extend all the way back to the bridge during the evening peak.

There have been numerous proposals to widen existing East Bay highways or to build new ones. Caltrans, which is responsible for highway improvements along I-80, concluded in a 1984 EIS that it could not build the 14-18 lanes that would be required to accommodate projected demand for the currently congested segments of I-80 (MTC 1987a, p.21). The EIS found that, because the space between Berkeley's Aquatic Park and San Francisco Bay is so limited, it would be necessary to double deck I-80 south of I-580/Knox Freeway. Because of the high cost and visual impact of an elevated highway at this location, both Caltrans and local planning officials rejected this alternative.

* This congestion has worsened since the section of I-880 leading from the bridge was destroyed in the earthquake.

Traffic assignments reported in the EIS also indicated that increasing the capacity of the westbound bridge approach would result in longer delays at the Bay Bridge Toll Plaza. As a result of these considerations, Caltrans developed an Operational Improvement Project for I-80 that includes proposals for new westbound and eastbound HOV facilities. While the proposal is currently (February 1989) in the design phase, Caltrans anticipates a long and difficult process of negotiation, and possibly litigation, with citizens and planning officials in the several affected communities, including Berkeley and Emeryville, before any of its proposals are implemented.

Caltrans's current westbound proposal provides for a new 3+ HOV lane carved out of the I-80 highway shoulder from Powell Street to West Grand Avenue. This new HOV lane would allow westbound buses and carpools to by-pass congestion on I-80 between Powell Street and West Grand Avenue. When they reach West Grand Avenue, buses and carpools would be able to use the existing far right HOV lane at the approach to the Bay Bridge Toll Plaza.

Another proposal for westbound I-80 would create HOV facilities in western Contra Costa County. In this scheme, a new 6.9 mile HOV lane would be built from Willow Road in Rodeo west (south) to the San Pablo Dam Road on-ramp (in San Pablo). The proposed facility would be a single, physically separated 12 foot wide HOV lane, with a 13-foot shoulder. Carpools and buses would be able to enter the facility at four access points, but would be able to exit only at the end.

Caltrans has also proposed building a new two-lane elevated HOV facility that would run from the Bay Bridge to the I-80 and I-580 interchange (Figure 4-1). There is some discussion as to whether this facility should be two-lane reversible or one lane in each direction. At the I-880/I-80 intersection, the two HOV lanes would split into single HOV lanes on I-580 East and I-80 East. If built, these HOV lanes would be the first eastbound bus/carpool facilities in the East Bay. Planners assume the proposed facility would be open to buses and carpools during the evening peak period, but would be restricted to buses during the AM peak. Caltrans hopes that providing the proposed eastbound HOV facilities will reduce the incentives for casual carpooling during the AM peak period and induce increased carpooling during the PM peak period.

Caltrans's plans for the I-80 corridor have been highly controversial. While most East Bay residents feel there is a need to increase the corridor's person carrying capacity and generally support the implementation of HOV facilities, there is considerable disagreement over how and where new HOV facilities should be provided. East Bay residents generally support adding HOV facilities as part of highway expansion programs, but residents and city officials in Berkeley and Emeryville oppose adding lanes to the highway, arguing instead for increasing the person carrying capacity of these facilities by converting existing general purpose lanes to HOV lanes.

Berkeley residents and officials are concerned about overdevelopment and the environmental impact of highway expansion, while those in Emeryville are primarily concerned with the impact of a huge elevated HOV structure that would literally fly over their city. Still other critics argue that it would be a waste of money to spend millions of dollars on discontinuous HOV lanes, as their main effect would be to simply move, rather than to eliminate, existing bottlenecks. They support a more comprehensive plan that would provide an uninterrupted HOV lane in the corridor.

The Golden Gate Bridge Corridor

As the journey-to-work data in Table 4-1 reveal, more than 44,000 North Bay, i.e. Marin and Sonoma County, residents commuted to jobs in San Francisco each day during 1980; 29,000 of them worked in San Francisco's central business district. In contrast to the East Bay to San Francisco corridor, there is no rail rapid transit service between the North Bay and San Francisco. While there is limited ferry service from Marin County to the CBD, virtually all trips between the North Bay and San Francisco use the Golden Gate Bridge.

The Golden Gate Bridge, Marin County's only direct vehicle access to San Francisco, was opened to traffic in 1937. The bridge is 1.7 miles long and approximately 62 feet wide; the single bridge deck is just wide enough to allow a tight six lane roadway. Since the early 1960's, the Golden Gate Bridge, Highway and Transportation District (GGBHTD) has implemented a number of measures in an effort to increase the bridge's effective capacity and to improve the flow of peak direction vehicles.

In 1963, GGBHTD began reversible lane operations as a way of increasing the bridge's effective peak hour capacity. This simple measure which provided four lanes in the peak direction and two in the off-peak direction in place of the previous 3-3 arrangement, increased the peak direction capacity by one third. Five years later, in 1968, GGBHTD further increased the bridge's vehicular capacity by implementing one-way toll collection. "Double" tolls are collected in the southbound direction at 11 toll booths at the San Francisco (south) end of the bridge. Golden Gate Bridge tolls, which for several years had been $1 Monday through Thursday and $2 on Friday, Saturday and Sunday, were recently (January 1989) changed to a flat $2 toll for all days of the week (all figures are nominal dollars).*

Transit and carpool mode splits for the Golden Gate Bridge are much lower than those for the Bay Bridge. This is true in spite of the option East Bay to San Francisco commuters have of using BART instead of the Bay Bridge for their commute. The combined bus and 3+ carpool share of AM peak period person trips on the Golden Gate Bridge has never exceeded 40 percent, a level reached in the early 1980's. In contrast, carpools alone carried 44 percent of Bay Bridge AM peak period commuters (Table 4-3) and additional 14 percent used express buses. If BART is added, 72 percent of AM peak period trips between the East Bay and San Francisco were by carpool or transit. Transit's share of AM (6-10 AM) peak period daily person trips on the Golden Gate Bridge peaked in 1982 at 26 percent. The 3+ carpool share of AM commute period person trips peaked between 1978 and 1982 at approximately 14 percent.

As the data in Table 4-5 reveal, 70 percent of the nearly 36,000 daily AM peak period person trips between North Bay and San Francisco using the bridge during 1987 were made in low-occupancy vehicles (less than three persons); only 11 percent were made in carpools (3+ private automobiles) and 19 percent were made by bus. Thus, 30 percent of AM peak period person trips using the Golden Gate Bridge in 1987 were made by bus or carpools as compared

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* Golden Gate Bridge commuters can also purchase commuter discount books at approximately 17% off regular tolls. Presently, 70 percent of southbound commuters use discount tickets during rush hours. This saves time as traffic flow is speeded when bridge officers do not need to return change. The price of these books was increased in June 1989 from $1.25 per ticket to $1.67 per ticket.

Table 4–5. Numbers and Shares of Golden Gate AM Peak Period Person and Vehicle Trips by Mode for Selected Years

Mode	Vehicles 1974	Vehicles 1980	Vehicles 1987	Persons 1974	Persons 1980	Persons 1987
Totals						
LOV	18,457	18,719	21,448	22,221	22,765	25,091
Carpool	922	1,523	1,057	3,238	5,438	3,963
Bus	207	420	476	8,534	8,797	6,862
Total	19,586	20,662	22,981	33,993	37,000	35,916
Percent						
LOV	94.2%	90.6%	93.3%	65.4%	61.5%	69.9%
Carpool	4.7%	7.4%	4.6%	9.5%	14.7%	11.0%
Bus	1.1%	2.0%	2.1%	25.1%	23.8%	19.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: GGBHTD, Five Year Plan, 1987.

to the 58 percent carpool/bus mode split for westbound AM peak period person trips on the Bay Bridge in the same year (see Tables 4-5 and 4-3). This large difference between the two bridges in HOV modal share is due to several factors: a much more limited history of transit service and ridership between Marin County and San Francisco; higher North Bay levels of household income and car ownership (Marin County has the highest per capita income of any county in California at $24,554); and much smaller volumes of worktrips between the North Bay and San Francisco than between the East Bay and San Francisco (see Table 4-1).

As the data in Table 4-5 and Figure 4-4 reveal, AM peak period bus ridership declined by 22 percent and the number of carpoolers declined by more than 27 percent between 1980 and 1987. During the same period, the number of person trips in low occupancy vehicles (LOVs) using the bridge during the AM peak period grew by 10 percent. These data indicate that the share of North Bay commuters using LOVs has been increasing. This contrasts sharply with experience in the late 1970's and early 1980's when the implementation of a number of transit improvements and HOV priority schemes induced drivers of single occupancy vehicles to shift to transit and carpools.

The decline in transit and HOV mode share after 1982 is clearly evident in Figure 4-5, which displays indices (1974=100) of AM peak period person trips by year and mode for the period 1974-1987. As these data indicate, total Golden Gate Bridge AM peak period person trips grew fairly steadily for most of the 1974-1982 period before peaking at just over 39,100 trips in 1982. Then in the next five years (1982-1987), AM peak period person trips declined steadily to less than 36,000 in 1987.

In terms of the index shown in Figure 4-5 (1974=100), person trips declined from 115 to 106, where 1974 equals 100. In contrast, during the same 14-year period, Golden Gate Bridge AM peak period vehicle trips grew fairly steadily except for a slight decline during 1979 and 1980, which coincided with the first oil shock, sharply higher gas prices, and, perhaps most im

Figure 4-4. Mode Splits of Golden Gate Bridge AM Peak Period (Southbound) Person Trips by Year, 1974-1987

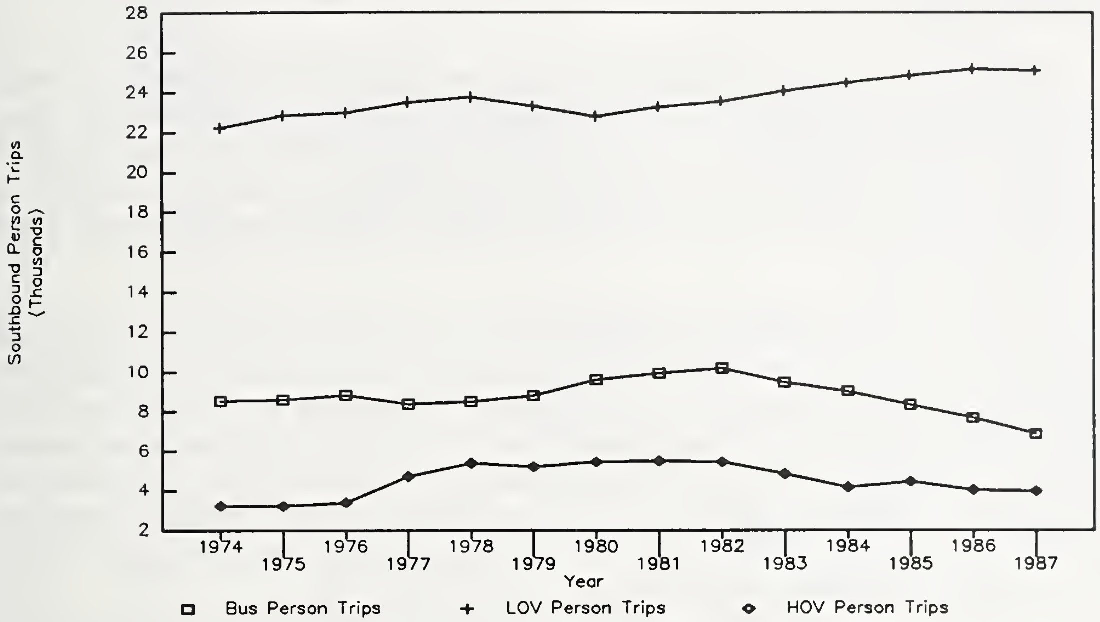
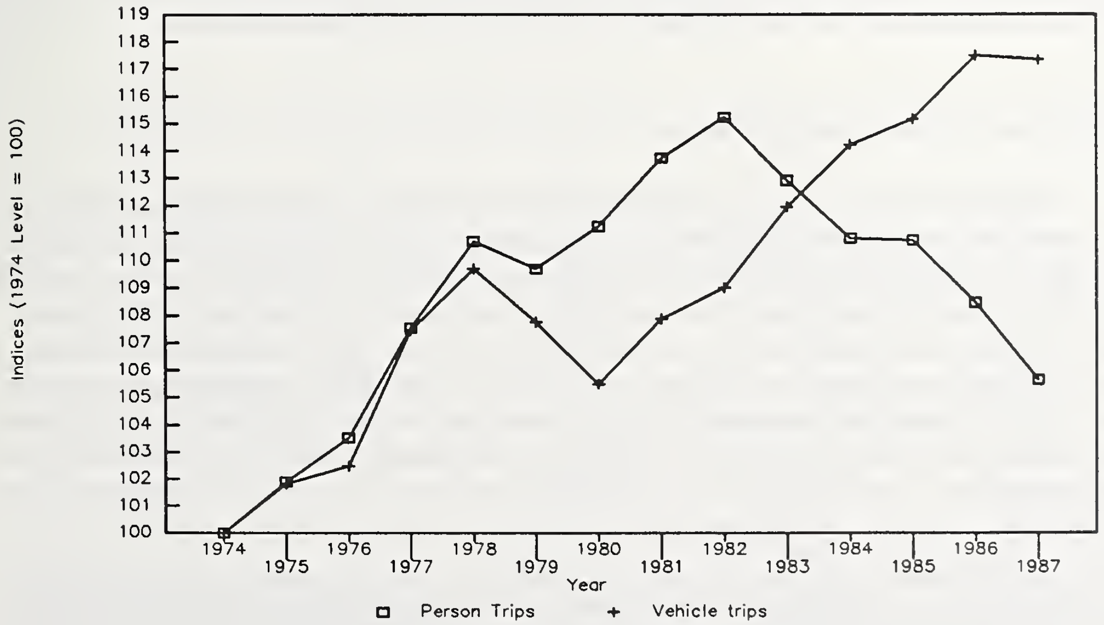


Figure 4-5. Index (1974 Levels = 100) of Golden Gate Bridge Westbound AM Peak Period Person and Vehicle Trips by Year, 1974-87



portantly, gas shortages. Even with this temporary decline during 1979-80, AM peak period vehicle trips increased by 17 percent between 1974 and 1987, from 19,586 to 22,981. These peak period volumes of nearly 23,000 vehicles produced serious congestion, as each of the Golden Gate's four narrow peak direction lanes carried more than 1,400 vehicles per hour during the morning peak period.

Somewhat surprisingly, at the same time peak period vehicle traffic increased, average in-vehicle travel times for peak period commuters appear to have decreased somewhat. Average trip times between the Waldo tunnel and Lyon Street declined from 9.5 minutes in 1985 to 8.5 minutes in 1986 (GGBHTD, 1987, p. 33). The Waldo tunnel is located just north of the Golden Gate Bridge and Lyon Street is the first local street in San Francisco after traffic leaves the Presidio (Figure 4-6).

The improvements in travel times described above are apparently due to voluntary peak spreading by private automobile users. While the number of vehicles using the Golden Gate Bridge during the four hour morning peak period has increased over the past five years, the number using the bridge during the two heaviest hours (7-9 AM) has actually decreased as auto drivers have increasingly shifted to the two "shoulders" (6-7 AM and 9-10 AM). It appears that many private automobile commuters using the Golden Gate Bridge have adjusted their departure and arrival times and continue to commute by private automobile rather than carpool or use transit during the two hours of heaviest travel.

Transportation officials in the North Bay emphasize that the Golden Gate Bridge has been operating at or near capacity during both the morning and evening peak periods since the early 1970's, if not before.* The region's transport planners have therefore understood for many years that further increases in peak period tripmaking can only be achieved through greater transit use and carpooling or by encouraging peak spreading. As the data presented above suggest, policies to encourage more carpooling and transit use by North Bay commuters have met with varying degrees of success. As an aid to understanding this history, we now consider the HOV priority scheme currently in effect in the corridor and its implementation.

Current Marin County HOV Facilities

In Marin County, U.S. Route 101, the county's only major north-south highway, runs from the north end of the Golden Gate Bridge and extends northward through the cities of Sausalito, Mill Valley, San Rafael, and Novato, and continues north through Sonoma County through Petaluma and Santa Rosa (Figure 4-7). The highway has either four or five lanes in each direction, with the number depending on the terrain and the availability of right-of-way at each point. Caltrans is responsible for Highway 101 planning, construction, maintenance and operations. GGBHTD owns and operates the Golden Gate Bridge and its approaches and provides bus and ferry services in the corridor through its Golden Gate Transit (GGT) and Golden Gate Ferry divisions.

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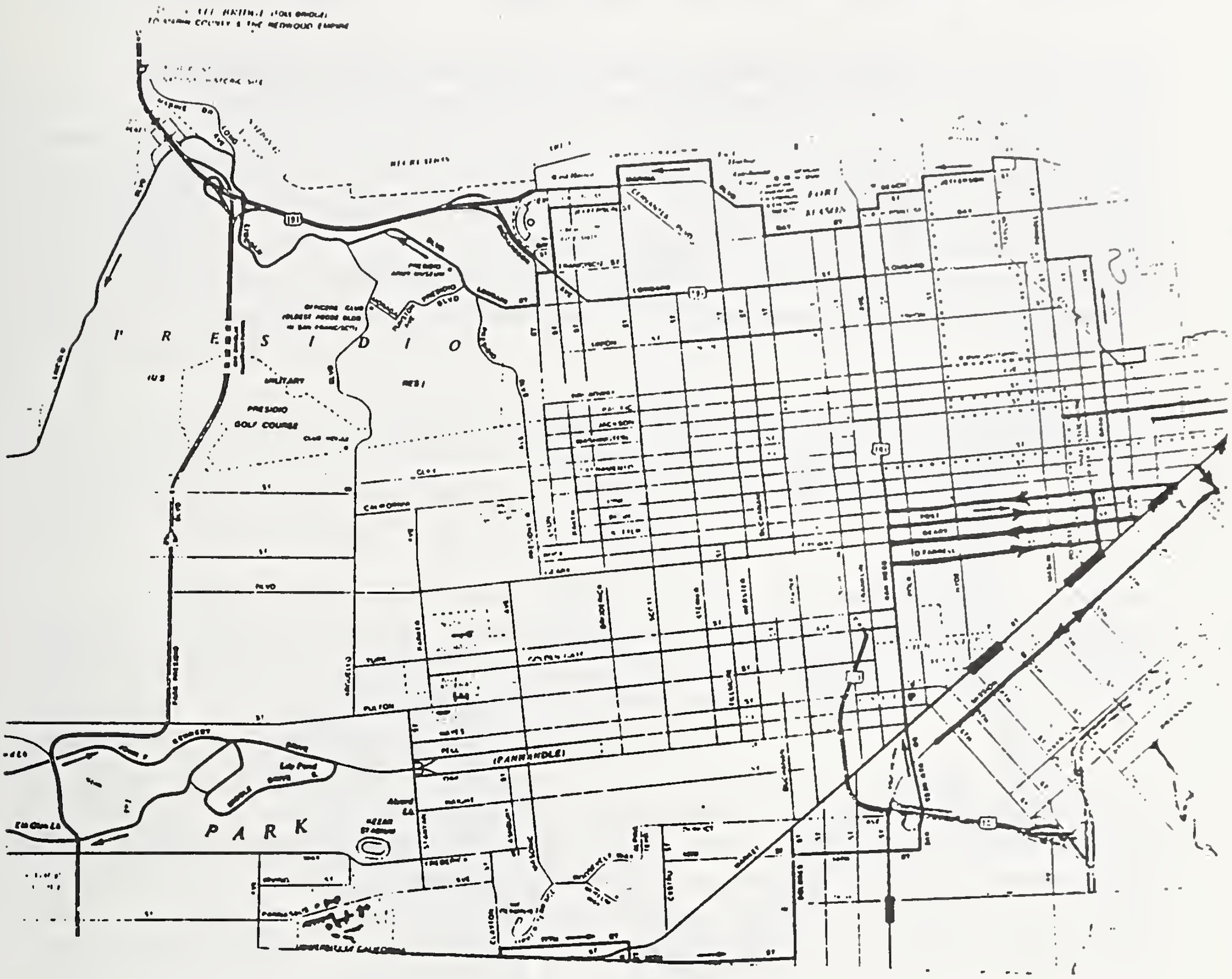
* The best time series data on bridge use is for southbound vehicle and passenger traffic because this is where tolls are collected. Southbound flows are more critical, in the evening San Francisco streets cannot deliver northbound vehicles fast enough to exceed capacity on the bridge. However, capacity problems in the evening are developing because southbound PM traffic is now exceeding the capacities of the two lanes allocated to reverse commute traffic.

Figure 4-6. Map of S.F. City Streets off the Golden Gate Bridge



At the present time, the North Bay to San Francisco HOV priority measures consist of:

(a) Golden Gate Bridge toll exemptions for high occupancy vehicles. Vehicles with 3+ persons are exempt from tolls during weekday peak periods (6-9 AM and 4-6 PM) and do not have to stop at the toll booths; and

(b) nine discontinuous miles of HOV lanes for buses and 2+ carpools on Highway 101.*

Highway 101's HOV lanes, which are the leftmost lanes in both the north and southbound directions, operate only during peak periods in the peak direction. The Highway 101 HOV lanes are not barrier separated; instead they are designated by diamonds and signage.

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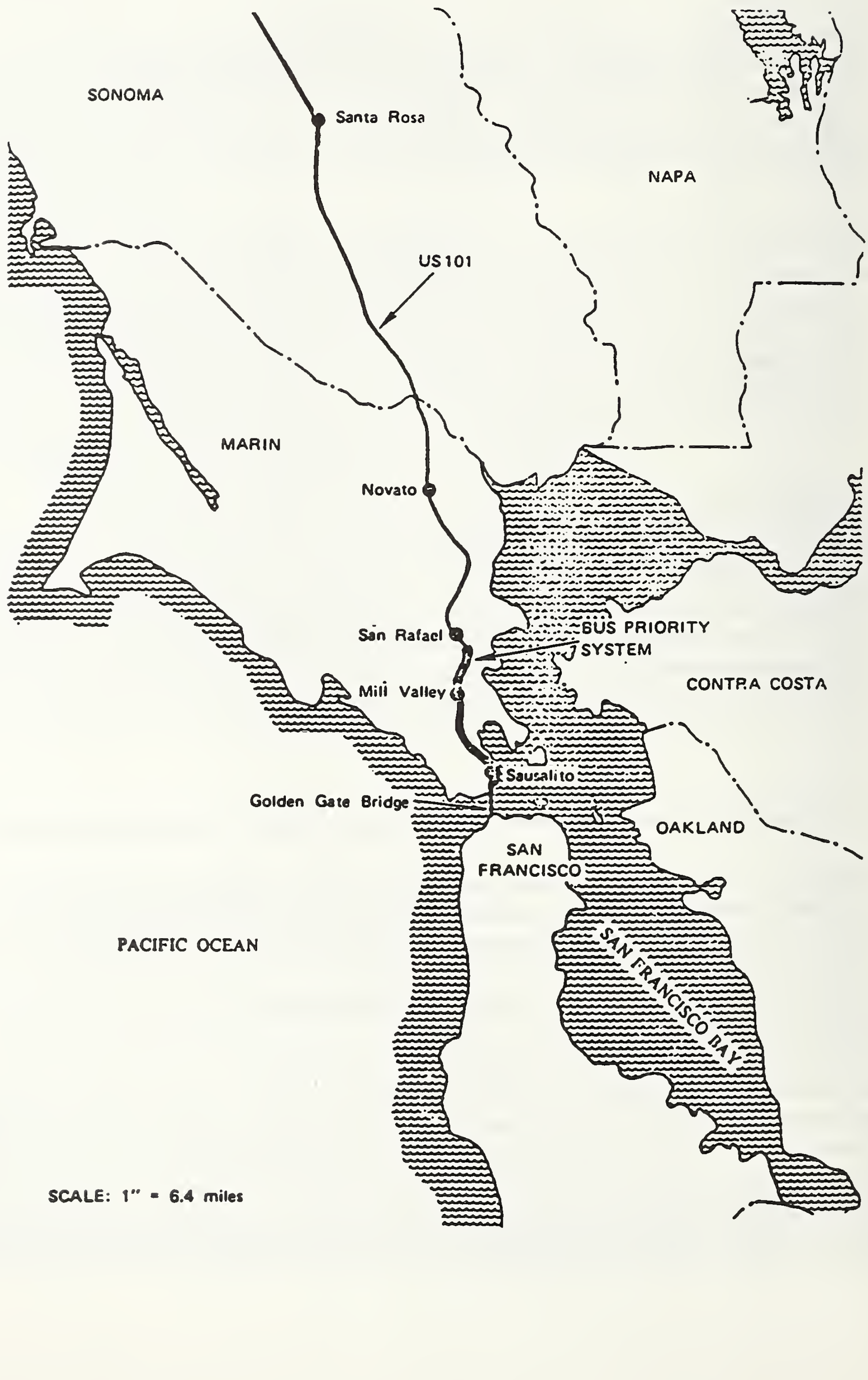
* In late 1988, Caltrans, in response to pressure from Marin County supervisors and claims that the 3+ designation caused the lanes to be underutilized, changed the carpool definition from 3+ to 2+. Vehicles must still have three or more occupants, however, to be exempted from Golden Gate Bridge tolls.

Figure 4-7.

The Golden Gate Corridor and Marin County HOV Lanes



During non-peak periods and in the off-peak direction, the HOV lanes are used as general traffic lanes.

The Highway 101 HOV lanes have been implemented in stages since 1974 in conjunction with highway widening projects. Bay Area transportation officials we interviewed, with few exceptions, took the position that HOV lanes should only be implemented at the time when highways are widened. In support of this view they pointed to the problems encountered by Caltrans when it implemented the abortive Santa Monica Freeway diamond lane project in 1976 (see Chapter 9). At that time Caltrans attempted to "take away" an existing peak direction lane for HOV use. Because of Caltrans's policy, no carpool or bus lanes have been provided on the sections of Highway 101 where limited right-of-way or high construction costs have prevented Caltrans from widening the road.

The first segment of HOV lanes in Highway 101 begins 3.75 miles north of the Golden Gate Bridge and extends for five miles. This segment was initially implemented in 1974 as a concurrent-flow bus lane. The first five mile stretch of HOV lanes is followed by a four mile "gap," and then by a second four mile stretch of HOV lanes.

The discontinuous nature of the Highway 101 HOV lanes tends to move rather than eliminate bottlenecks. As a result, buses and carpools using the HOV lanes obtain only small time savings from using them. The primary benefit of the HOV lanes appears to be a reduction in the variability in travel times, as the HOV lanes frequently permit buses and carpools to bypass congestion caused by accidents or other incidents.

As the discussion at the beginning of this section suggests, Highway 101 HOV lanes have had little impact on travel patterns in the corridor. This is made particularly clear when the Highway 101 experience is contrasted with the larger impacts observed for the Bay Bridge travel patterns. Time savings and other benefits from bus and carpool use simply appear to have been too small to have had much of an effect on carpooling or transit use in the North Bay - San Francisco corridor.*

Implementation of HOV and Bus Priority Measures

As in the East Bay, the state government has consistently encouraged local officials to implement measures that would encourage transit use and carpooling. North Bay transportation planning, for example, was significantly affected by the previously mentioned 1970 California State Legislature directive to Caltrans to study experimental bus and carpool lanes. As a result of these studies, Caltrans began operating an experimental PM peak period northbound contra-flow bus lane in Highway 101 in September 1972.

The northbound Highway 101 contra-flow buslane extended from the end of the Golden Gate Bridge, where buses entered the lane through a slip ramp in the median, to a point 3.9 miles north on Highway 101. Design and implementation of this PM peak period contra-flow lane was a cooperative effort by Caltrans and the Golden Gate Bridge, Highway and

* Only part of the North Bay - San Francisco bus services have benefited directly from the addition of the HOV lanes. Since the HOV lanes are located in the far left hand (fast) lane, they can only be used by thru buses. As a result, buses stopping at the bus stops located at highway off-ramps cannot use the HOV priority lane.

Transportation District. The project's capital cost in 1989 dollars included $472,000 to prepare the lanes and $66,000 for signage; operating costs in the first year totaled $155,000.

The Highway 101 contra-flow lane was separated from southbound traffic by plastic stanchions placed in a buffer lane. Therefore, in contrast to New York's XBL (Chapter 3), the Highway 101 contra-flow lane entailed the use of two reverse peak directions (southbound) highway lanes. Taking away two of the four southbound lanes during the PM peak (one for the contra-flow bus lane and one for a buffer), was not viewed as much of a problem because off-peak direction bridge traffic was already limited to two lanes.

Because of steep grades, up to seven percent at certain points, and general concerns about safety, use of the Highway 101 contra-flow lane was limited to buses with permits and only specially trained drivers were allowed to use the lane. Speeds were limited to 40 mph and buses were required to turn on their flashers. The only exit from the contra-flow lane was at the end of the lane where buses from the contra-flow lane used a slip ramp through the median and shoulder to merge with northbound traffic.

The Highway 101 contra-flow lane only operated during evening peak hours as the most serious congestion during the morning peak period occurred at the toll booths and at the approach to the toll plaza rather than on Highway 101. During the morning peak period, Highway 101's four southbound lanes were well matched to the bridge's four lanes. As a result, an AM peak period southbound contra-flow lane on Highway 101 would have provided only small benefits at best. In addition, buses on the Waldo Grade are slowed more by the steepness of gradient than by traffic levels. A southbound contra-flow lane would not address this problem and thus it would have a minimal impact on congestion and bus speeds.

While benefits from the Highway 101 contra-flow lane were modest, so were its costs. The lane was quickly implemented at low cost, and it had no discernable effect on traffic in the reverse commute direction. Travel time studies of the contra-flow lane completed in 1975, indicated that during periods of normal traffic flow, bus speeds in the contra-flow lanes were actually slightly less than speeds in the general traffic lanes. Vehicles using the northbound freeway lanes adjacent to the contra-flow lane averaged just under 50 mph, while buses using the contra-flow lane averaged 40 mph. At the same time, travel times for buses using the contra-flow lanes were less variable, permitting buses using the lane to provide more reliable service. When serious congestion, particularly accidents, occurred, buses using the contra-flow lane maintained higher speeds than vehicles using the general traffic lanes.

Because of restrictions "inherent" in the contra-flow operations and a limited demand for transit in the corridor, fewer than 150 buses an hour used the facility.* Golden Gate Transit officials point to the 40 mph contra-flow speed limit as one of the reasons the lane was not more successful. Another factor limiting the contra-flow lane's potential was that buses serving residential areas within two miles of the bridge were unable to use the lane because the only exit from the lane was at its end. Limited use of the lane and a change of administration in Sacramento, caused Caltrans to discontinue the contra-flow lane in 1983. Caltrans's action illus-

* Some argued that the operating restrictions, including 40 mph speed limit and buffer lane, were too severe. Not a single fatality occurred in the contra-flow lane's 9-year history.

trates the inherent vulnerability of such priority schemes to changes in state and local administrations and public attitudes.

Concurrent-flow Lane

In May 1973, Caltrans implemented a 0.9 mile concurrent-flow bus-only extension of the Highway 101 contra-flow lane. This lane, shown in Figures 4-7 and 4-8, permitted buses to by-pass heavy congestion at the Richardson Bridge off-ramps. It was implemented when Caltrans widened the same section of highway from six to eight lanes. During a subsequent highway widening project, Caltrans extended the concurrent-flow bus lane an additional 2.9 miles to the north and implemented the first morning peak period priority scheme, a 3.7 mile concurrent-flow southbound bus lane in the same section of highway. These concurrent-flow lanes were ordinary freeway lanes that were designated as bus-only lanes during the morning (south direction) and evening (north direction) peak periods. The bus-only lanes had no special markings, buffer lanes, or physical separation, but were signed at 800 foot intervals.

It was hardly a coincidence that Caltrans implemented concurrent-flow bus lanes at the same time they widened the highway. Marin County's growth management plan, completed in the early 1970's, contained a "no highway expansion" policy statement. This led Caltrans to package its Highway 101 widening projects, which included the concurrent-flow bus lanes, as transit improvements rather than highway expansion projects.

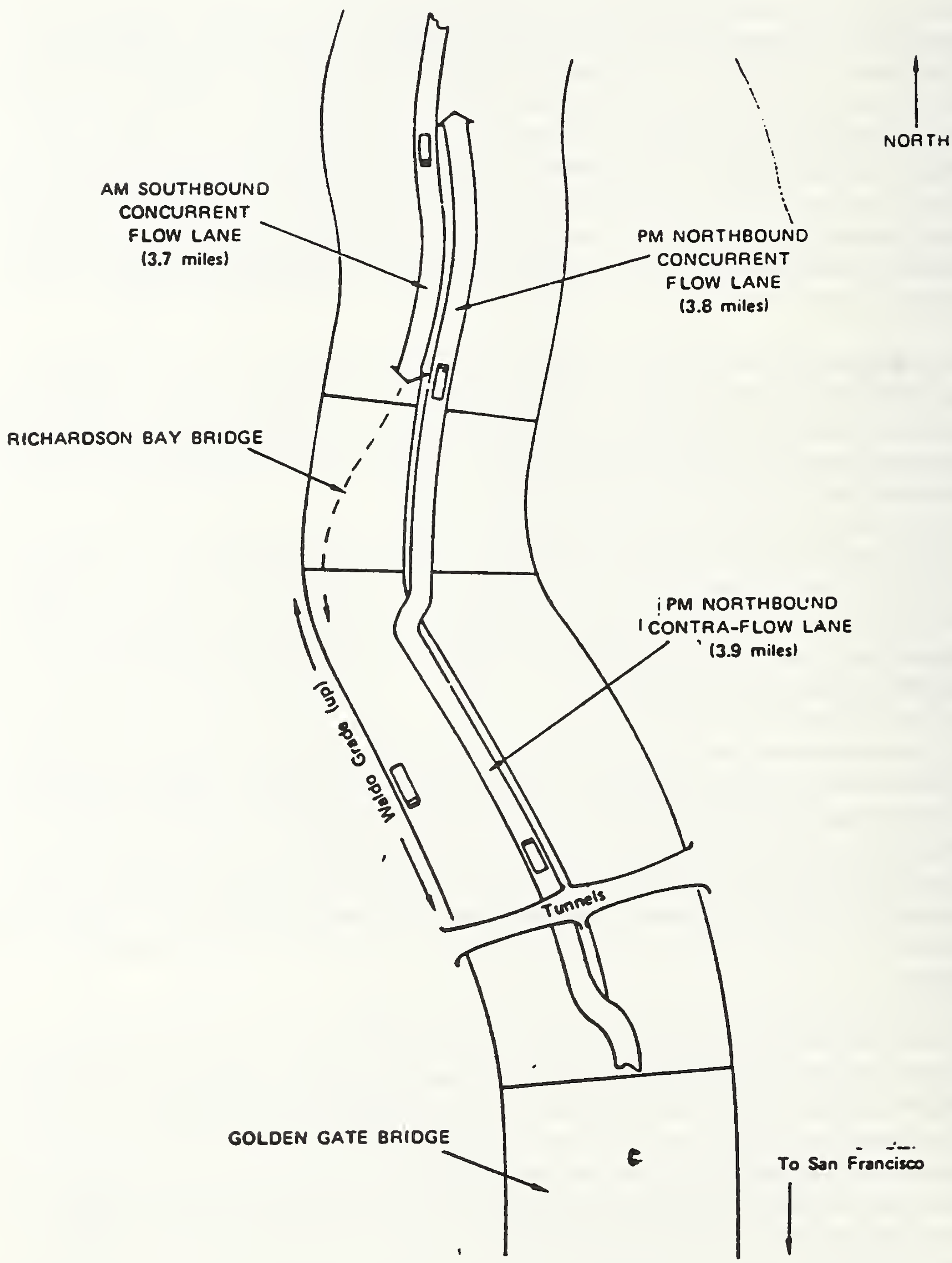
North Bay bus riders clearly benefited from the implementation of the concurrent-flow bus lanes, which were not subject to the contra-flow lane's 40 mph speed limits. When they were first introduced, northbound buses using the first 3.7 miles of concurrent-flow bus lane saved about five minutes per trip during the evening peak period. During the morning peak period, they saved about seven minutes.

Once again, state policy had an important impact on transportation planning in the corridor. California Assembly Bill 918, passed in 1975, directed Caltrans and local transportation agencies to provide carpooling incentives by establishing preferential lanes for carpools on major freeways in metropolitan areas. Starting in April 1976, GGBHTD eliminated all tolls for 3+ carpools using the Golden Gate Bridge during peak periods, and three months later, Caltrans began allowing 3+ carpools to use the concurrent-flow bus lanes on Highway 101. Because of concerns about head-on collisions, however, carpools were still prohibited from using the contra-flow lane.

There is some evidence that while Caltrans's decision to allow carpools to use the concurrent-flow bus lanes and GGBHTD's decision to eliminate peak period tolls for carpools led to a significant increase in carpooling, they also adversely affected bus ridership. In the year (1976) before carpools were allowed to use the concurrent-flow lanes and were exempted from peak period tolls, AM peak period bus ridership was about 8,800 person trips, close to 25 percent of all person trips on the bridge. As the data in Figure 4-4 indicate bus patronage fell by more than five percent in the year after carpools were given access to the concurrent-flow priority lanes and free tolls, to below 8,400 person trips in fiscal year 1977, causing a decline in the bus modal share to just under 23 percent. During the same period, 3+ carpools grew by more

Figure 4-8.

Schematic of Marin County HOV Lanes



than 38 percent from 3,400 to over 4,700 person trips, and the carpool share of total AM peak period person trips increased from 10 to 13 percent.

Allowing carpools to use the concurrent-flow lanes, however, did not lead to a decline in the use of LOVs, i.e. vehicles with one and two occupants. The number of LOV person trips made during the AM peak period actually increased by over 500 to 23,500 during the first year after carpools were allowed to use the formerly bus-only concurrent-flow lanes. It thus appears that the primary effects of allowing carpools to use the concurrent-flow lanes and eliminating peak hour tolls for carpools were to reduce bus ridership and to divert some carpools from the general traffic lanes to the concurrent-flow lanes. The action did, however, reduce congestion somewhat.

Allowing carpools to use the concurrent-flow priority lanes increased the effective capacity of Highway 101 and thereby reduced congestion in the general traffic lanes. After the concurrent-flow lanes were opened to carpools, AM peak period bridge vehicle volume increased five percent to 21,000. During the same period time savings for concurrent-flow lane users, compared to general traffic lane users, fell to only 0.6 minutes southbound and 1.6 minutes northbound (Caltrans, 1977, p. 12). The contra-flow bus lane continued to operate for some time after the concurrent-flow bus lanes were opened up to carpools. Nonetheless, transit use continued to decline as the trip time and reliability advantages of bus transit over private vehicles became less significant.

Bus Services in the North Bay - San Francisco Corridor

The Golden Gate Bridge, Highway and Transportation District (GGBHTD) is a special purpose district created by an act of the state's legislature in 1928 to finance, design, and build the Golden Gate Bridge. The District consists of San Francisco, Marin, Sonoma, Del Norte, most of Napa, and a portion of Mendocino Counties. In 1930, District voters approved a $795 million bond issue (in 1989 dollars, $35 million in 1930 dollars) to build the Golden Gate Bridge, which was first opened to vehicular traffic in 1937. Interest and principal payments were paid entirely from bridge tolls until the last of the construction bonds were retired in 1971.

Before 1969, transit services from Marin and Sonoma Counties to San Francisco were limited to private, unsubsidized commuter bus services provided by Greyhound. In 1969, the California State Legislature directed the Golden Gate Bridge and Highway District, as the GGBHTD was then known, to develop a mass transportation program for the district. The legislature's action is explained in part by worsening congestion in the corridor and on the bridge itself, but the more compelling reason was the imminent retirement of the district's bonds, a development that would free up substantial revenues which could be used for other purposes. The legislature added "Transportation" to the district's title to emphasize its new responsibilities for public transit.

While the district's first priority remained operation and maintenance of the Golden Gate Bridge, it agreed to use its surplus toll revenues to subsidize transit services between San Francisco and Marin and Sonoma Counties. In 1970, the district took its first halting step into the public transportation field when it began commuter ferry service between Sausalito and San Francisco. Two years later the district began operating express buses from Sonoma and Marin

Counties to San Francisco using surplus toll revenues to cover revenue shortfalls not already financed by state and federal subsidies.

Golden Gate Transit (GGT) began bus service on January 1, 1972 with a fleet of 132 "upscale" buses selected to appeal to the well-to-do North Bay to San Francisco CBD commuters. GGT took over many of the services previously operated by Greyhound, which had for many years provided commuter service from communities along 101 to downtown San Francisco. Greyhound was happy to abandon the routes as they had become unprofitable. At the end of the first month, GGT coaches carried 5,500 daily passengers from Marin and Sonoma Counties as compared to the 4,300 passengers a day carried by Greyhound.

North Bay bus ridership between FY 1974 and FY 1982 exhibited a modest upward trend. During this time AM peak period (6-10 AM) bus ridership rose from about 8,500 to close to 10,200. The bus share of AM peak period passenger trips over the same period varied from a high of 26 percent to a bit over 22 percent. As Figure 4-4 indicates, bus ridership reached its peak in 1982, both in terms of total passenger trips and the share of corridor trips. Bus passenger trips and the bus share of total trips have steadily declined since 1982.

The bus share of corridor trips declined from a high of 26 percent in 1982 to 19 percent in 1987, while total bus ridership declined by 32 percent over the same nine year period to just under 6,900 AM peak period trips in 1987. As our previous discussion indicated, the decline in bus patronage appears to reflect numerous factors, but the small time savings for bus riders, the decision to open the former bus-only concurrent-flow lanes to carpools, the free tolls for carpools over the bridge, the development of the Larkspur ferry, and the spreading of the peak appear to be the most important causes.

GGT currently operates 22 commuter routes and 195 scheduled bus trips each morning between Marin and Sonoma Counties and San Francisco. GGT has two categories of commuter routes: (a) basic routes that operate throughout the day, and do not use the concurrent-flow lanes, and (b) commuter routes that collect passengers in residential neighborhoods and enter the concurrent-flow lane at various points. Unlike AC Transit's transbay routes and most XBL buses (Chapter 3), all GGT commuter buses must use congested city streets when they reach San Francisco.* The average GGT commuter bus trip between the toll plaza and the CBD (in this case the previously discussed Transbay Terminal) makes three stops and takes 24-29 minutes.

There are several possible explanations for GGT's failure to attract more bus passengers. The most important appears to be that GGT buses do not provide commuters with any significant travel time savings, relative to carpools or LOVs. In fact, the design of the GGT routes and the Highway 101 HOV lanes ensures that most potential bus riders have significantly longer travel times by bus than they would have by competing modes.

The design of GGT's bus routes reflects a policy decision to emphasize residential collection and coverage. In its most recent five-year plan GGT states:

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* GGT buses do not use MUNI's bus lanes on San Francisco city streets.

> most transbay bus routes do not provide direct bus service comparable to travel by automobile. The routes are designed to obtain maximum coverage over a wide area of dispersed travel origins and destinations to provide for basic mobility (GGBHTD, 1987, p. 56).

Another problem with GGT's bus services is caused by the discontinuous nature of the existing HOV lanes. During peak periods, buses and carpools encounter the serious congestion on those segments of Highway 101 that do not have concurrent-flow HOV lanes. The most serious problem with GGT express services, however, is presumably the delays its buses experience on the streets of San Francisco and the time spent in serving intermediate destinations in San Francisco.

GGT's has recently responded to ridership declines with a series of service reductions. It's latest Five Year Plan states:

> In response to declining transbay commute bus patronage, the District will continue its gradual reduction of commuter bus services until a level of stability is reached.... In fiscal year 1988, commuter bus service will be reduced by about 17 percent with the cancellation of 64 commute bus trips. Headways will be increased on nearly all commute bus routes (GGBHTD, 1987, p.vi).

While the reasons for declining bus ridership over the last five years are not clear-cut, it is even less obvious that GGT's decision to reduce service is the appropriate response. The Golden Gate Bridge and Highway 101 are currently operating at or very near capacities; approximately 23,000 vehicles use the four peak direction lanes during the morning peak period. At these volumes, bridge traffic moves slowly and is highly vulnerable to accidents, breakdowns, and other incidents which frequently create long delays.

Without adding lanes, the only ways to increase the bridge's person moving capacity are to increase bus ridership, carpooling, and/or to further spread the peak. The bridge's narrow deck and lanes work against converting one of the four peak period lanes to a HOV lane, but there are other measures, such as metering traffic onto the bridge with bus/carpool priority, that would most likely be as, if not more, effective. Other proposals to increase the person carrying capacity for the bridge and the Highway 101 corridor are discussed below.

Increasing Effective Capacity

There have been several recent proposals to reduce congestion on the Golden Gate Bridge. One of the most significant is a recent (January 1989) doubling of the Monday-Thursday tolls from one to two dollars. GGBHTD plans to use these increased toll revenues to reduce commuter bus fares, to avoid further service reductions, and to restore previously discontinued service. In June 1989, the price of the ticket books used by most HOV commuters was also raised.

Before the toll increase, District Director Stephan Leonoudakis announced that bus fares would be reduced by 20-30 percent in the year following the toll increase and by 30-40 percent by fiscal year 1991. He argued that the combination of lower fares and higher bridge tolls

would "bring thousands of motorists out of their cars and onto buses." He added that the toll increases would affect bus ridership in three ways, by permitting fares to be reduced, by raising the cost of auto commuting and by improving bus travel times and frequencies (San Francisco Chronicle, 1988).

It is still too early to fully assess the effects of the recent bridge toll increase on transit ridership and auto use. Preliminary data suggest, however, that the higher tolls have caused a substantial decline in bridge use by private automobiles and a modest rise in bus and ferry patronage. GGBHTD's mid-January spot check showed that 23,039 cars crossed the bridge during a typical AM peak in January 1989, down from 24,987 in January 1988. But while the number of AM peak private auto crossings fell by 1,948, AM peak period bus ridership increased by only 338 persons (from 6,144 to 6,482) and ferry ridership increased by only 85 persons (from 1,545 to 1,630).

As of early 1989, GGBHTD officials were encouraged by the preliminary results. The reported rise in bus ridership occurred in spite of a nearly simultaneous decision to change the carpool criteria for use of Highway 101's HOV lanes from 3+ to 2+ and it reverses a 6-year decline in GGT bus ridership to San Francisco (San Francisco Examiner, 1989).

Double-Decking the Golden Gate Bridge

Plans for a second traffic deck on the Golden Gate Bridge have been discussed on and off ever since the span opened to traffic. A recent proposal, for example, would provide four general traffic lanes on each of two decks plus a reversible bus lane on the upper deck. Excepting the reversible bus lane, traffic on each of the two decks would be single-direction, as on the Bay Bridge.

Even though the second deck, with the proposed 4-4-R1 scheme would increase the bridge's total vehicle capacity by 50 percent, vehicular capacity in the peak direction would be increased by only 25 percent, i.e., from four to five lanes, as the current reversible lane arrangement already provides four lanes in the peak direction during peak periods.* Depending on how the reversible bus lane was operated and the levels of congestion experienced in the general traffic lanes, however, the reversible exclusive bus lane could significantly improve peak direction bus speeds and dependability, relative to vehicles using the general traffic lanes.

The idea of a second deck has been the source of a bitter North Bay - San Francisco split for more than 20 years. Bridge district board members from some of the counties located north of San Francisco have consistently supported proposals for a second deck, while San Francisco board members and their supporters have opposed them on grounds that a second deck would merely increase the number of vehicles using San Francisco's already heavily congested streets. Opponents of the scheme also point out that as soon as the second deck is completed, Marin and Sonoma County motorists would undoubtedly begin to lobby for changes in bridge operations that would provide additional general traffic lanes in the peak direction.

* Of course, if the proposed reversible bus lane was very successful, the effective increase in the bridge's person carrying capacity would be much larger.

Safety has become the major selling point of the second deck. In fact, instead of referring to the scheme as the second deck plan, its advocates refer to it as the "Safety Deck Plan." (San Francisco Chronicle, 1988). The bridge's narrow lanes and, more importantly, the absence of a median barrier separating on-coming streams of traffic makes head-on collisions a legitimate concern. In fact, four motorists were killed on the bridge in 1987. On the assumption that the proposed one-way operations were implemented and then retained, a second deck would, in fact, largely eliminate the possibility of head-on collisions.*

Prospects for a bridge expansion in the near future are dim. The recent Highway 101 Corridor Study gave low priority to increases in North Bay - San Francisco crossing capacity, other than ferries and buses, through the year 2005. In addition, no local or regional jurisdictions have taken official actions in support of increasing the capacity of the Golden Gate Bridge.

There are also a number of less well developed double decking proposals for the Golden Gate Bridge which include rail, either BART or LRT. In these proposals, use of the second deck would either be restricted to rail or shared by rail and motor vehicles. The original plan for BART included a line to Marin County over the Golden Gate Bridge; the plan was dropped when engineering studies showed the bridge could not safely carry the heavy BART trains. Even so, support for a Marin County BART line has re-emerged. Even a moments reflection, however, makes it clear that the engineering considerations are only the beginning. The more serious questions are where BART trains would run once they got to Marin County, and whether they would attract enough riders to justify the heavy expense.**

Proposals for an Exclusive Transit Guideway

Ever since GGBHTD first began to provide transit services in 1971, it has had plans to develop exclusive fixed guideway transit in the Highway 101 corridor. In its most recent draft 5-year plan (1989), the authority identifies fixed guideway transit as an element of the District's capital project. The current proposal would have GGBHTD purchase the abandoned Northwestern Pacific Railroad right-of-way between Corte Madera and Novato in Marin County with future plans for purchasing 46 miles of right-of-way from Novato through Santa Rosa and up to Healdsburg, in Sonoma County (see Figure 4-5). GGBHTD would initially build a 13-mile exclusive busway between Corte Madera and Novato.

The proposed exclusive busway would allow bus users to bypass the most heavily congested sections of Highway 101 in central Marin County. GGBHTD estimates that such a bypass would save bus riders from northern Marin and Sonoma Counties a minimum of 15 minutes per trip and greatly improve schedule reliability. These time savings and greater dependability would increase ridership, at the same time the shorter round trip time would reduce bus operating costs and improve the system's finances (GGBHTD, July 1987).

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* Depending on the design of the proposed reversible exclusive bus lane, particularly if it was barrier separated, some potential for head-on collisions between buses and autos might remain with the two deck scheme.

** Estimates are that a BART line over the Golden Gate Bridge from San Francisco to Marin would cost more than $1 billion and take a decade or more to build. There is an alternative proposal by BART to put rail service to Marin County in an underwater tube instead of on the Golden Gate Bridge. The costs of this scheme have been estimated at $2.3 billion. (San Francisco Chronicle, 1989, p. A4).

GGBHTD estimates the busway project would cost $60.4 million and $4.6 million per mile in 1989 dollars. The 1989 dollar costs include $24 million for purchase of the right-of-way and design costs and an additional $36.4 million for construction of the busway from Corte Madera to Novato

As might be expected, there are also proposals to build an LRT system in the corridor.* There is considerable pressure to design the busway for conversion to LRT. Experience in Pittsburgh and Ottawa indicates that making this provision is likely to increase busway costs by 5-10 percent. In a June 1989 memo to the 101 Corridor Action Committee, the staff for the 101 Corridor Strategic Plan recommended that the Larkspur (the site of the ferry terminal adjacent to Corte Madera) to Santa Rosa corridor be served by a combination of LRT and diesel commuter rail cars.

The LRT trains, which would be expected to carry 12,000 daily passengers, would run from the ferry landing in Larkspur with eight stops through Marin County to Novato. The diesel rail cars would run from Santa Rosa to Larkspur with only limited stops in Marin County and would be expected to carry 5,000 passengers per day. The LRT is estimated to cost $234 million, while the diesel rail cars would add another $124 million (both in 1989 dollars). The diesel rail cars were substituted for the LRT in Sonoma County in order to accommodate Sonoma County's request for a less expensive proposal.

Both LRT and diesel rail have some obvious disadvantages in this situation. Nearly all users of the system would be making trips to or from downtown San Francisco. Since there is no realistic prospect for eventually continuing an LRT line through southern Marin County across the bridge and into the San Francisco CBD, transit passengers would have to transfer to either buses or the Larkspur Ferry to reach downtown. On the suburban end, moreover, most commuters who currently walk to (from) their bus stops would have to drive to an LRT station or use a feeder bus. An LRT system would thus require nearly all San Francisco bound passengers to transfer once at the southern terminus and many others to transfer twice, from a feeder bus to the LRT and then to another bus or ferry for the trip to downtown San Francisco.

Conclusion

Transportation planners in the San Francisco Bay Area have faced limited options in developing transit schemes because of the area's geography and strong commuter preference for private vehicle travel. Despite this handicap they have succeeded in achieving substantial increases in the passenger volume capacity of the region's bridges through aggressive and innovative uses of bus and carpool lanes.

* Marin County has retained Barton Aschman Associates, Inc. to carry out a study of the corridor and to recommend a strategic plan for implementation of corridor-wide improvements through the year 2005.

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Chapter 5: Ottawa's Experience with Bus Rapid Transit

Introduction

OC Transpo, Ottawa-Carleton's public transit authority, is constructing the most extensive exclusive busway system in North America. The system currently consists of approximately 8.7 miles of exclusive busway with 13 stations, 2.3 miles of mixed use parkway, and an additional 1.4 miles of exclusive bus lanes and five stations within the downtown area (Bonsall 1987). A further six miles of exclusive busway and eight stations will be completed by 1993 for a first stage of 19.2 miles and 26 stations. The authority, moreover, is actively considering further extensions of the system and construction of a bus tunnel in the central area.

Daily ridership on the Ottawa busways averages 200,000 per day, a figure that exceeds the ridership on any new North American light rail system by a large margin.* The 200,000 riders per day using Ottawa's 12.4 miles of exclusive busway, moreover, compares favorably with the 134,000 riders per day using the 19.7 mile BART system, the 179,100 riders per day using the 26.8 mile MARTA (Atlanta) system, or the 386,400 riders per day using the far more extensive 60.5 mile WMATA (Washington D.C) heavy rail system (Pickrell, 1989).**

Development of the Ottawa Busway

Development of OC Transpo's exclusive busway system is continuing and the authority expects to have completed a 19.2 mile "first stage" busway system with 26 stations by 1993. The projected capital cost of this first stage system is $373 million 1989 U.S dollars.*** The latter figure translates into a cost of $19.4 million per mile (including station construction at an average of $3.7 million per station).**** As we noted previously, OC Transpo is actively considering the construction of a CBD bus tunnel, similar to the one under construction in Seattle, to improve downtown distribution and reduce congestion in the central area.

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* The most recent estimates of weekday ridership and route miles for six new LRT systems are: Buffalo, 29,000 per day (6.4 miles); Pittsburgh 19,800 (10.5 miles); Portland 19,000 (14.9 miles); Sacramento 13,200 (29.3 miles); San Diego 24,500 (20.4 miles) and San Jose, 6,000 (17.8 miles) (Pickrell, 1989).

** Due to rounding, the length of the first stage of the transitway currently operating when given in miles and/or segments varies from 12.4 to 12.8 miles.

*** All dollar figures from OC Transpo were originally denominated in Canadian dollars. The completed segments are constant 1989 Canadian dollars, while the uncompleted segments include an inflation factor to 1993. Construction cost estimates in current year Canadian dollars are converted into constant 1989 Canadian dollars using the Toronto ENR Construction Cost Index for July of each year, operating and other costs are converted using the Canadian CPI. 1989 Canadian dollars are converted into 1989 U.S. dollars using the average 1989 exchange rates of $1.184 Canadian to $1.000 U.S..

**** The estimated $338 million cost of Ottawa's 19.4 mile First Stage system obviously compares favorably with $736 million for Buffalo's 6.4 mile LRT system, $634 million for Pittsburgh's 10.5 mile LRT system, or $271 million for Portland's 14.9 mile system (Pickrell 1989) (all dollar amounts are in 1989 U.S. dollars). In comparison to heavy rail systems, Ottawa on average carries 12 percent more persons per day than Atlanta's system, which cost eight times as much, more than 50 percent of the riders carried by Washington's system, which cost nearly 13 times as much, and to choose a particularly bad comparison, it carries more than 5 times as many persons per day as Miami's heavy rail system, which cost 3 times as much.

The 19.2 mile first stage system consists of the five linked busways shown in Figure 5-1, i.e. the Southwest, West, Central Area, Southeast, and East Busways. Construction began in 1981 and the first two sections, the Southwest and part of the Central Area Busways, were opened in December 1983. The West Busway and the second segment of the Central Area Busway were both opened in November 1984. The first section of the East Busway, moreover, opened in 1987, and OC Transpo expects it to be completed in late 1989. The Southeast Busway will be completed in three sections by 1993.

During the 1990's, OC Transpo plans to extend the system an additional 16.7 miles to three growth areas beyond the central city. After the year 2000, the authority plans to add still another 7.4 miles of exclusive busway, including a CBD bypass that will allow some busway services to bypass downtown altogether. The Region's Official Plan refers to an "ultimate system" of 43.4 miles of exclusive busways.

Busway Characteristics

In some respects, Ottawa's exclusive busway system operates just like a modern light rail system with it's vehicles, which in this case happen to be buses, operating on mostly grade-separated, exclusive two-way fixed guideways and stopping at stations for passenger loading and unloading. In contrast to light rail systems, however, most of the vehicles operate off the busway as well. Indeed, most users of the system ride express and limited stop bus routes that provide no-transfer service between Ottawa's residential areas, the CBD, and other major trip generators. This operating concept is shown in Figure 5-2.

Cross-sections of the Ottawa busways, shown in Figure 5-3, are similar to those for Pittsburgh's busways. The most common configuration consists of two 13 foot wide travel lanes, one in each direction, with two 7.8 foot wide shoulders. The right-of-way widens from 43 feet to 75 feet at stations to allow for a fenced median, which is needed to discourage at-grade crossing of the busway by passengers, and an additional lane in each direction that permits express and limited-stop buses to bypass some or even all busway stations. Buses operate up to their maximum operating speed of about 55 mph, but are restricted to 30 mph in station areas.

The busways are designed so that Ottawa's bus rapid transit system will be able to accommodate a large increase in passenger demand in the future. System planners originally designed the busways so that they could be converted to light rail, but this criterion has since been changed to heavy rail, if future levels of ridership make such conversion necessary. The proposed CBD bus tunnel is also being designed to permit conversion to heavy rail.

OC Transpo's decision to provide for the future conversion of its busways to heavy rather than light rail, reflects its current view that bus rapid transit has sizeable operational cost and service advantages relative to light rail, and that it would make sense to forego these advantages only if future system ridership reached levels that could no longer be accommodated by the bus system. These high volumes would, of course, exceed both busway and light rail capacities, and thus nothing would be gained from conversion to light rail. OC Transpo General Manager John Bonsall (1989a) estimates that providing for possible future conversion of the busways to heavy rail added 5 to 10 percent to the capital costs of the busways, excluding stations.

Figure 5-1. First Phase Ottawa Transitway System

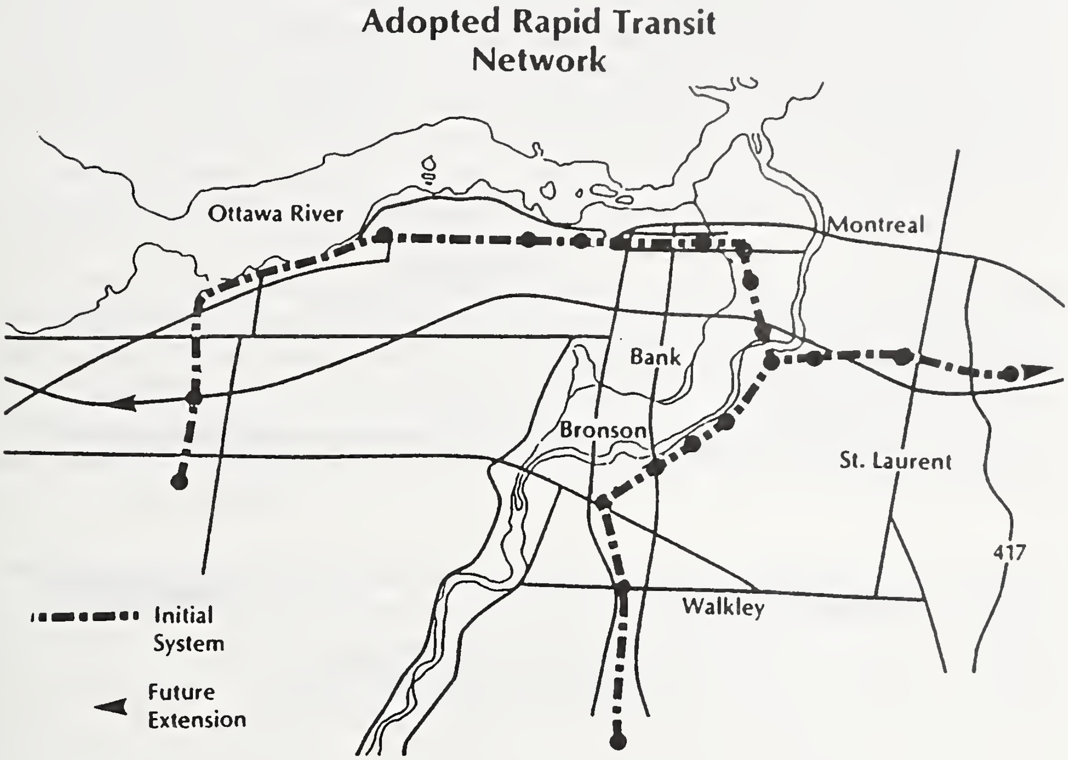


Figure 5-2. Busway Operation

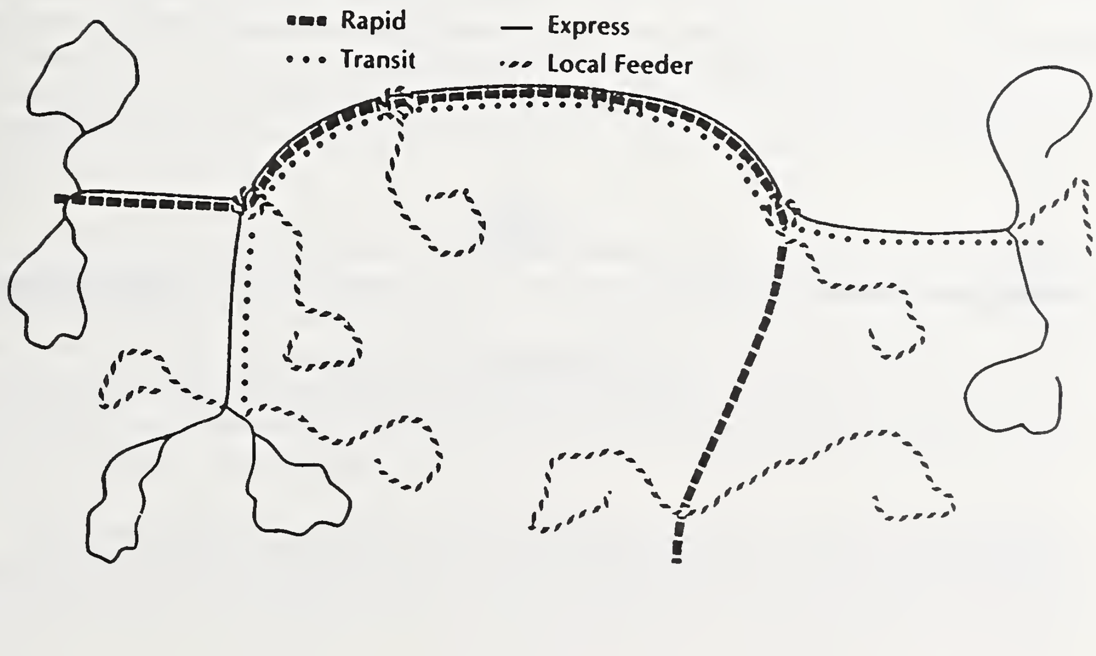
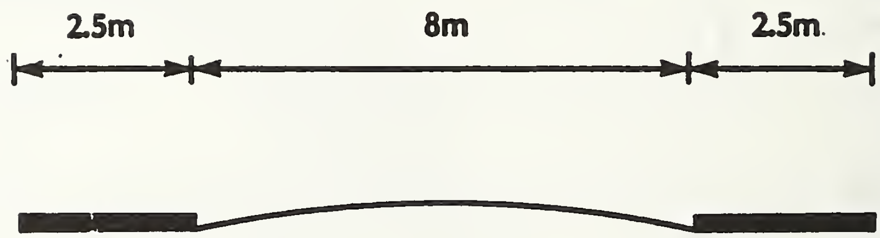


Figure 5-3.

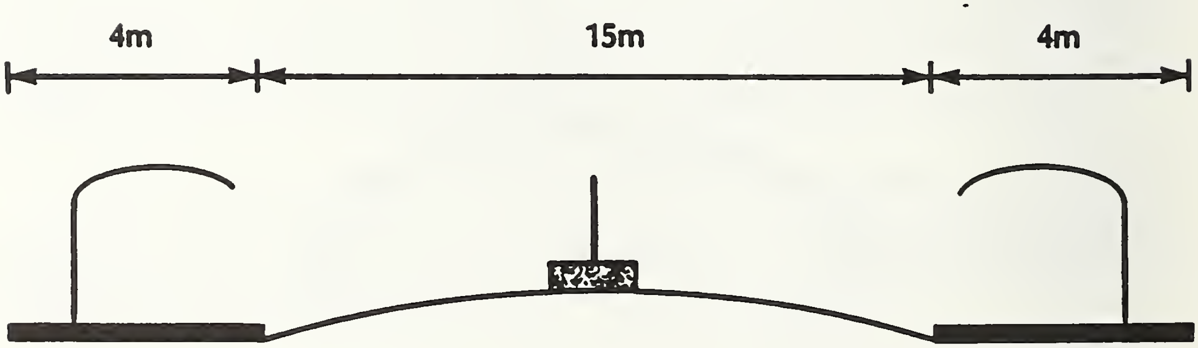
Typical Busway Cross-Sections

Transitway



Design Speed 80km/hr.

Station



Design Speed 50km/hr.

The currently operated 12.4 mile busway system is fully grade-separated for most of its length. The only exceptions are the 1.4 mile downtown section, which consists of concurrent flow reserved bus lanes, 2.3 miles of parkway operation in mixed traffic, and a few intersections with streets in outlying areas where modest traffic volumes do not justify the cost of grade separation. In the downtown, the transitway currently operates on a pair of one-way streets; each of these streets carries 180-200 buses per hour during the peak hour. The downtown bus lanes occupy the second lane from the curb on four lane wide one-way streets. This arrangement leaves the curb lane available for bus stopping areas, and parking and loading areas. OC Transpo operates both standard and articulated buses on the system.

As in Pittsburgh, OC Transpo operates two kinds of services on the busways: (a) a large number of routes that collect their riders in residential areas and use the busway for only part of their journey, and (b) a smaller number of routes that operate exclusively on the busway. Indeed only one route operates solely on the busway at the present time. This busway-only route uses articulated buses and runs from one end of the East-West Busways to the other (Figure 5-2) at three minute headways during peak periods and 5-15 minute headways during off-peak periods. It stops at all busway stations.

Feeder buses with 15 minute peak period and 30 minute off-peak headways operate on a time transfer system to and from the stations and connect to the frequent busway-only service. In addition, there are four all-day integrated feeder-busway routes with headways of between seven and 15 minutes which operate for part of their routes over the central section of the busway system. Finally, an additional 59 express and limited stop routes use the busways during peak periods. For part of their journeys, these services pick up passengers on local residential streets and at park-and-ride facilities before entering the busway on special access ramps. The express and limited stop services do not make all stops on the busways. About 180 buses per hour use the busway in the peak direction during peak periods.

Busway stations, which are unmanned, provide passenger loading and unloading, protection from inclement weather, and information services. Fares are collected on board the buses; however, over 75 percent of OC Transpo passengers currently use monthly passes and cash passengers must pay the exact fare (drivers do not provide change). These procedures, and particularly the extensive use of passes, significantly reduce boarding times, increase system capacity, and reduce both trip times and operating costs. Fares vary by time of day and area served.

Station platforms on the grade-separated portions of the busway are 180 feet long, providing sufficient space for up to three buses to load and unload at the same time. Winters are quite bitter in Ottawa and each station consists of a series of small shelters linked by covered walkways. The shelters are designed to accommodate the 30, 39 and 59 foot buses operated by OC Transpo. Shelter door openings are designed in such a way that the buses' front and rear doors line up with the shelter doorways. During the cold Ottawa winters the shelters are heated for the comfort of waiting passengers.

While the typical busway station has two parallel platforms, the designs of individual stations are varied to accommodate the specific requirements of the stop, including its location in

the system and the extent to which the station is served by feeder buses.* Some of the busway stations are very similar to those found on light and heavy rail systems. The system's largest station is part of a regional shopping center; its platforms are located in a tunnel at the basement level of the shopping center.

In contrast to Houston's transitways and many other bus and rail rapid transit systems in the United States, park-and-ride facilities are not a significant factor in Ottawa. Nearly all users of the busway walk to bus stops, where they board either feeder buses or integrated feeder-busway services. OC Transpo currently provides only two 700 car lots for busway passengers, although the authority does plan to provide an additional 2,000 spaces within the next five years.

Daily ridership on Ottawa's busway currently averages about 200,000 per day and, according to Bonsall (1989a, p. 10), "ridership at the peak load points, in the peak direction, have reached 9,000 passengers per hour." As shown in Table 5-1, daily ridership on Ottawa's still uncompleted first stage busway system, far exceeds the ridership for any new light rail system in North America.

The light rail systems in Table 5-1 are ranked by passengers per route mile. As these data indicate, Toronto's light rail system, which began service in 1892, has the highest ridership per route mile per day of any North American light rail system, with 7,237 daily riders (presumably boardings or unlinked trips) per route mile. With 330,000 boardings, Toronto's 45.6 mile system also has the most daily riders.

Both Toronto with 330,000 boardings and Boston with 220,000 boardings carry more passengers each day than Ottawa's exclusive busway system. But these light rail systems are also much more extensive. Comparing passengers per route mile, Ottawa's 12.4 mile busway system has more than twice as many passengers per route mile as Toronto's light rail system, 16,800 versus 7,237 riders per route mile per day. By this criteria, San Francisco has the second most productive light rail system with 6,802 boardings per route mile; its per mile rate, however, was only 40 percent of Ottawa's at the time APTA assembled these data.

Actual construction costs of building OC Transpo's exclusive busways appear to be very close to the design estimate costs.** This is very different from the experience with federally funded rail systems in the United States, where actual construction costs have typically been much greater than projected costs. As we discuss in greater detail in Chapter 12, a recent UMTA funded study by Pickrell (1989) found that the actual capital costs of eight federally funded new rail systems in the United States tended to be substantially higher than projected costs.***

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* At the present time, the system has two stations with island platforms where buses can load and unload from either side. For the first, the island platform serves as the temporary terminus of the busway; OC Transpo will add a second parallel platform when the busway is extended. For the second, the island platform serves as a junction between busway and feeder bus routes. Its design permits maximum flexibility in bus movements.

** We should be very clear that we have not carried out the kind of searching investigation of actual and projected costs done by Pickrell (1989) of recently completed federally funded rail systems in the United States. Instead, we have accepted OC Transpo's claims at face value.

*** Of the eight systems, only the Pittsburgh LRT with actual constant dollar capital costs of $634 million, as compared to projected costs of $713 million, cost less than projected. Cost overruns for the remaining seven systems averaged nearly 50 percent and ranged from a 16 percent cost overrun for the $193 million Sacramento LRT to 83 percent for the $8.1 billion dollar Washington D.C. Metrorail (all figures are expressed in 1989 dollars).

Table 5–1. Passenger Per Route Mile for North American Light Rail Systems and Exclusive Busways

City	Year First Opened	Route Miles	Daily Passengers	Passengers Per Route Mile
Exclusive Busway				
Ottawa	1983	12.8	210,000	16,406
Pittsburgh	1977	10.3	46,500	4,515
Light Rail				
Toronto	1892	45.6	330,000	7,237
San Francisco	1887	19.7	134,000	6,802
Edmonton	1978	6.4	25,000	3,906
Boston	1897	58.6	220,000	3,754
Newark	1935	4.3	14,000	3,256
New Orleans	1893	6.6	21,000	3,182
Calgary	1981	16.8	36,000	2,143
Philadelphia	1892	92.9	127,000	1,367
Portland	1986	15.4	20,000	1,299
San Diego	1981	20.4	26,000	1,275
Cleveland	1920	13.5	17,000	1,259
Pittsburgh	1891	22.5	28,000	1,244
Sacramento	1987	18.3	16,000	874
San Jose	1987	20.6	11,000	534
Buffalo	1985	6.4	3,000	469

Sources: APTA. (1987a), "Light Rail Transit."
APTA. (1987b), "Transitways."
OC Transpo, 1988 Transit Fund and Inter–Departmental Corres., 10/87

Constant dollar expenditures for Ottawa's 19.2 mile first stage busway system through 1988 were approximately $280 million in 1989 Canadian dollars (or $237 million in 1989 U.S. dollars). The estimated capital cost of the entire first stage busway system, to be completed in 1993, is projected at $442 million (1989 Canadian dollars), or $373 million in 1989 U.S. dollars, including an allowance of 5 percent per annum for future inflation; this translates into $19.4 million (1989 U.S. dollars) per mile of busway. The estimated system capital costs include station construction which will average about $3.7 million (1989 U.S. dollars) per station. Recent cost projections by OC Transpo indicate that project expenditures during the 1989-93 period will peak in 1989, when about 28 percent of the projected current dollar outlays will occur. In 1990, about 23 percent of the total budget will be expended in 1990, while 10 percent of the budget will be spent in 1992 and beyond.

As Table 5-2 reveals, actual construction costs for the busways themselves have been slightly lower than projected costs. Actual construction costs were below estimated costs for the first four completed busway segments, and the fifth, the East Busway, appears to be on budget.

Annual busway maintenance, much of which is snow removal, averaged about $2.1 million (1989 Canadian dollars) in 1988, which is about $106,000 per mile for the roadway and

Table 5–2. Busway (Right–of–Way) Construction Costs
(millions of 1989 US dollars)

Corridor	Length (Miles)	Year Opened	Projected Costs	Actual Costs	Actual/ Projected
Southwest	1.9	1983	$32.0	$31.7	0.99
West	2.9	1984	$47.8	$46.2	0.97
Central	0.6	1984	$20.1	$19.4	0.97
Southeast	0.9	1983	$27.1	$26.6	0.98
East	6.5	1987	$101.9	$101.9	1.00
All	12.8		$229.0	$225.9	0.99

Source: OC Transpo, 1988 Transit Fund and Inter–Departmental Correspondence, Oct. 1987

$49,000 for each station, in 1989 U.S. dollars the values are $1.7 million, $89,300, and $41,500 respectively. System operating costs of the busway as of October 1987, averaged 3.9 cents (1989 Canadian dollars) per seat-mile for direct operating costs and 9.0 cents per seat-mile when all vehicle and right-of-way capital costs are included (Bonsall, 1987), 3.2 cents and 7.6 cents in 1989 U.S. dollars.

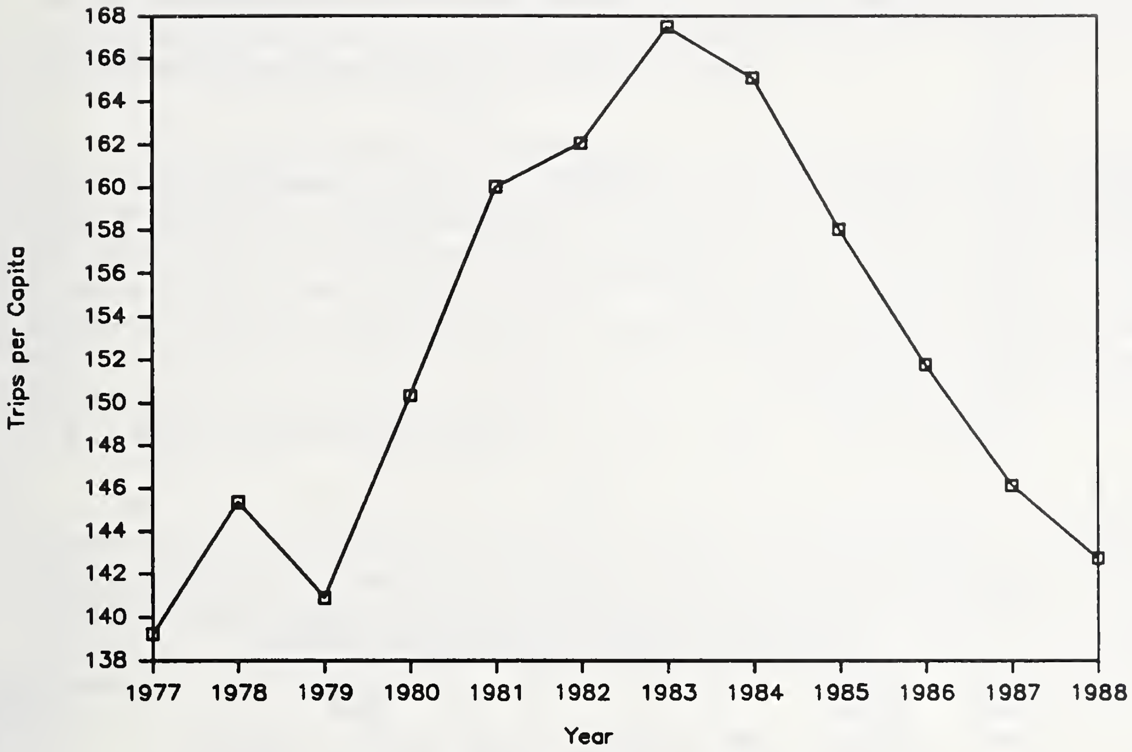
Funding

The Province of Ontario has paid for a bit less than 75 percent of the capital cost of Ottawa's busway system. The subsidy formula provides for 75 percent of allowable capital costs, but a small percentage of costs were deemed "ineligible." In addition to capital subsidies, Ontario also pays up to 50 percent of the operating deficit of public transit authorities as determined by a theoretical revenue/cost target which varies by regional transit operator. The province has established a revenue/cost target of 65 percent for OC Transpo and shares in any deficit below the target figure. In recent years the province has, in fact, provided an operating subsidy equal to about 19 percent of OC Transpo's operating costs. Funds to pay the local share of capital projects and operating costs deficits are obtained from property taxes.

Ridership and Overall Performance

As is true of other Canadian cities, Ottawa has much higher levels of transit use than cities of comparable size and age in the United States. Thirty percent of all work trips in Ottawa in 1980 were made by transit, as compared to 5 percent in Toledo, a United States metropolitan area of comparable size (U.S. Bureau of Census, 1980). In contrast to most, if not all, transit systems in the United States, OC Transpo managed to increase ridership in both absolute and per capita terms between 1977 and 1983; since 1983 ridership per capita has fallen to a point just above 1977 levels. Thus, as Figure 5-4 illustrates, annual riders per capita increased from 139 per capita in 1977, to 160 per capita in 1981, and to a peak of 167 per capita in 1983 before declining to 143 per capita in 1988.

Figure 5-4. OC Transpo: Annual Ridership Per Capita (1977-1988)



This pattern is repeated in Figure 5-5, which presents data on linked and unlinked trips during the first 12 years of OC Transpo's existence. Between 1973 and 1984 OC Transpo achieved a 132 percent increase in transit ridership (linked trips); the new authority increased ridership from 37.5 million trips per year in 1973 to 87.2 million trips per year in 1984.* Since 1984, OC Transpo ridership has declined in every subsequent year in spite of the completion of a significant portion of its new exclusive busway system.

Accepting the linked trip data in Figure 5-5 and Table 5-3 at face value, they indicate that OC Transpo lost 8.4 percent of its riders between 1984 and 1988. Statistical analyses by Kain (1989) suggest increases in transfer rates between 1986 and 1988 may be an important factor in producing these declines.** Bonsall (1990), in reviewing both a draft of this chapter and Kain's (1989) econometric analyses of Ottawa's ridership disputed this interpretation.

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* While the overall gains in total and average ridership are due in part to OC Transpo's performance, improved land use and the aggressive use of planning controls (that far exceed any even contemplated in United States cities) may be even more important.

** Using the annual time series data for Ottawa shown in Table 5-3, Kain (1989) obtained a transfer rate elasticity of approximately minus .35. The transfer rate for OC Transpo services increased by 21 percent between 1984 and 1988. Multiplying the 21 percent increase in the transfer rate times -.35, the estimated transfer rate elasticity, suggests that as much as 7.4 percentage points of the 8.5 percent decline in OC Transpo ridership between 1984 and 1988 could have been avoided if the authority had been able to keep the transfer rates for its services at 1984 levels. This result does not imply that OC Transpo was mistaken in making the system changes that led to the higher transfer rates. Since these changes reduced operating costs per trip, it is possible that the resulting savings permitted service mile increases that more than offset the negative effects of higher transfer rates on ridership.

Figure 5-5. OC Transpo: Annual Linked and Unlinked Trips (1971-1988)

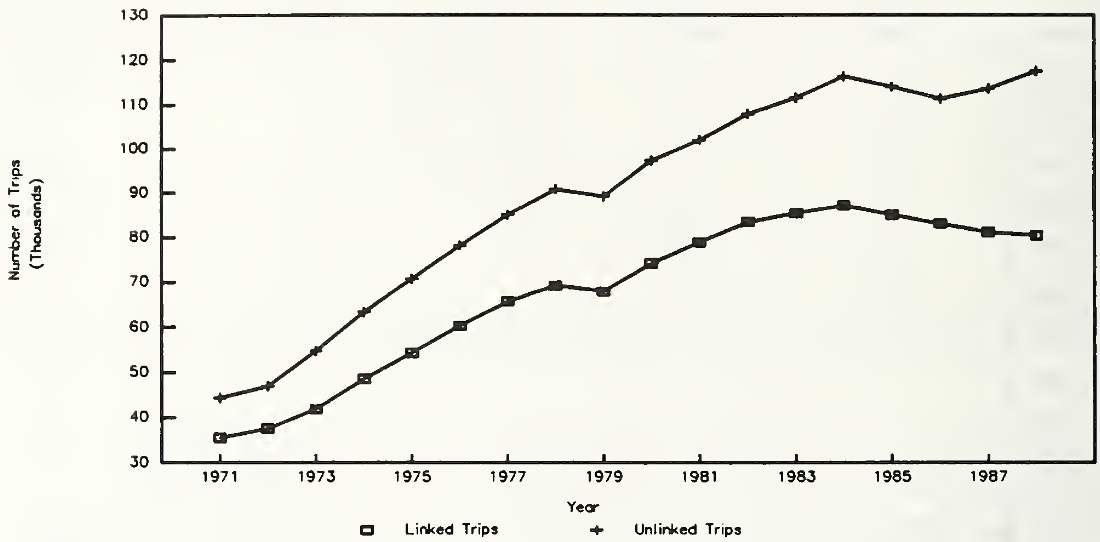

Table 5–3. Ridership, Bus Miles, Fares and Other System Characteristics OC Transpo, 1971–1988 (Canadian dollars)

Year	Annual Linked Trips (000)	Annual Unlinked Trips (000)	Bus Miles (000)	Average Fares Cur. $C	Average Fares 1989 $C	Ratio Revenue/ Operating Cost	Transfers Per Rev. Rider	Busway Miles	Average Peak Trip Length Miles
1971	35,514	44,346	8,658	$0.25	$0.88	1.07	0.25	0.0	3.5
1972	37,544	46,943	9,131	$0.25	$0.85	0.98	0.25	0.0	3.5
1973	41,808	54,710	11,735	$0.25	$0.79	0.83	0.31	0.0	3.9
1974	48,456	63,321	15,766	$0.25	$0.70	0.68	0.31	0.0	4.4
1975	54,260	70,758	19,679	$0.25	$0.64	0.57	0.30	0.0	4.5
1976	60,263	78,147	20,908	$0.28	$0.68	0.60	0.30	0.0	4.7
1977	65,725	85,012	22,179	$0.31	$0.68	0.63	0.29	0.0	4.8
1978	69,190	90,836	24,490	$0.33	$0.67	0.60	0.31	0.0	4.9
1979	67,912	89,158	25,171	$0.35	$0.65	0.58	0.31	0.0	5.1
1980	74,208	97,424	27,472	$0.37	$0.63	0.60	0.31	0.0	5.1
1981	78,884	102,086	28,596	$0.43	$0.64	0.58	0.29	0.0	5.3
1982	83,457	107,993	29,602	$0.49	$0.66	0.60	0.29	0.0	5.4
1983	85,423	111,518	30,392	$0.53	$0.68	0.61	0.31	3.0	5.5
1984	87,175	116,312	31,547	$0.56	$0.69	0.58	0.33	5.7	5.8
1985	85,014	113,920	30,610	$0.62	$0.74	0.59	0.34	6.0	5.9
1986	83,014	111,220	30,225	$0.68	$0.78	0.60	0.34	7.0	6.0
1987	81,104	113,546	30,268	$0.72	$0.79	0.57	0.40	7.8	6.2
1988	80,350	117,460	30,823	$0.75	$0.78	0.57	0.46	7.8	6.3
Average	67,739	89,706	23,736	$0.42	$0.72	0.66	0.32	2.1	5.0

Notes: 1988 constant dollar fare is $US 0.66 in 1989 US dollars

Source: OC Transpo, "Description of 1987 Operations and Operating Statistics," October 1988

Bonsall contends there are alternative explanations of the ridership declines and emphasizes that OC Transpo's peak hour ridership has not declined. He argues further that no direct services were eliminated and suggests that large increase in the transfer rates in 1987-88 were due to voluntary decisions by large numbers of OC Transpo passengers to transfer to the new, fast and frequent, busway services, rather than take the original and continuing slower direct services that continued to operate on the surface streets.

OC Transpo's success in improving service to downtown and increasing the share of worktrips carried by transit are even more noteworthy. The transportation plan developed for the region in the early 1970's identified increases in transit's share of worktrips as a primary objective. OC Transpo has met this goal; in 1988 it carried approximately 30 percent of all daily trips to work as compared with 16 percent in 1972. In addition, the most recent available data indicate that in 1987, transit carried more than 70 percent of peak-hour trips to downtown Ottawa (OC Transpo, 1987).* In spite of a significant growth in downtown activity, the transit share of worktrips to downtown has grown by enough to reduce the number of cars parked in the downtown, relative to the levels ten years ago.

OC Transpo achieved much of its impressive ridership gains during 1971-1984 by spending money and, in particular, by using the increased subsidies provided by provincial and regional governments to increase both the extent and frequency of transit services. As Figure 5-6 indicates, OC Transpo's bus service miles grew even more rapidly than its ridership during 1973-1984; bus miles of service increased by 169 percent while transit ridership grew by 132 percent between 1973 and 1984.

A large infusion of government subsidy dollars allowed OC Transpo to hold nominal fares constant at 25 Canadian cents per trip during its first five years of operation. As a result, real fares fell sharply between 1971 and 1975 and, as Figure 5-7 indicates, real fares per mile fell by even more, as average transit trip lengths increased as a result of OC Transpo's policy of aggressively extending service to previously unserved suburban areas.

After 1975, OC Transpo implemented annual fare increases that were about equal to inflation. Even so, a slight downward drift in real fares is evident for the 1976 to 1980 period and, as the data in Table 5-3 reveal, real fares in 1989 Canadian dollars reached a low of 63 cents per trip in 1980. Since 1980, OC Transpo has slowly raised fares in real terms; by 1988 per trip fares were almost identical in real terms to 1972 levels (78 cents per trip in 1988 versus 79 cents per trip in 1972, where both figures are expressed in terms of constant 1989 Canadian dollars, this is about 68 cents in 1989 U.S. dollars).

Peak period transit trips increased in average length from 3.5 miles to 4.5 miles per trip between 1971 and 1974. As the data in Figure 5-8 indicate, moreover, peak period trip lengths continued to increase steadily after 1974; from 4.4 miles per trip in 1974, they increased to 5.1 miles per trip in 1980, and finally to 7.8 miles per trip in 1987 and 1988. As a result, real fares per mile fell sharply between 1971 and 1975 and more slowly until 1984. As Figure 5-7 shows OC Transpo increased real fares per mile between 1984 and 1988; the authority also began to experience steady ridership declines during this period.

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* Supportive public policies, particularly federal government policies toward employee's parking, obviously contributed substantially to the increases in modal shares.

Figure 5-6. Index of Linked Trips and Bus Miles, 1947-1988 (Index is Measured Relative to Mean Value)

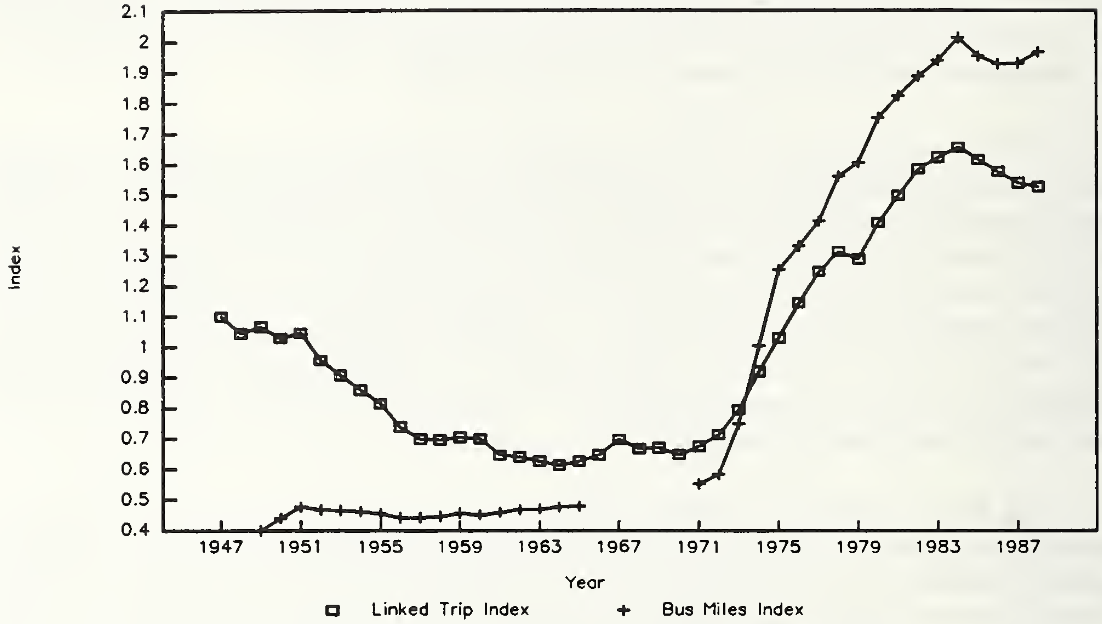


Figure 5-7. Indexes of Nominal Fares, Real Fares, and Real Fares Per Mile (Peak Hour Trip), 1971-1988 (Index is Relative to Mean Value)

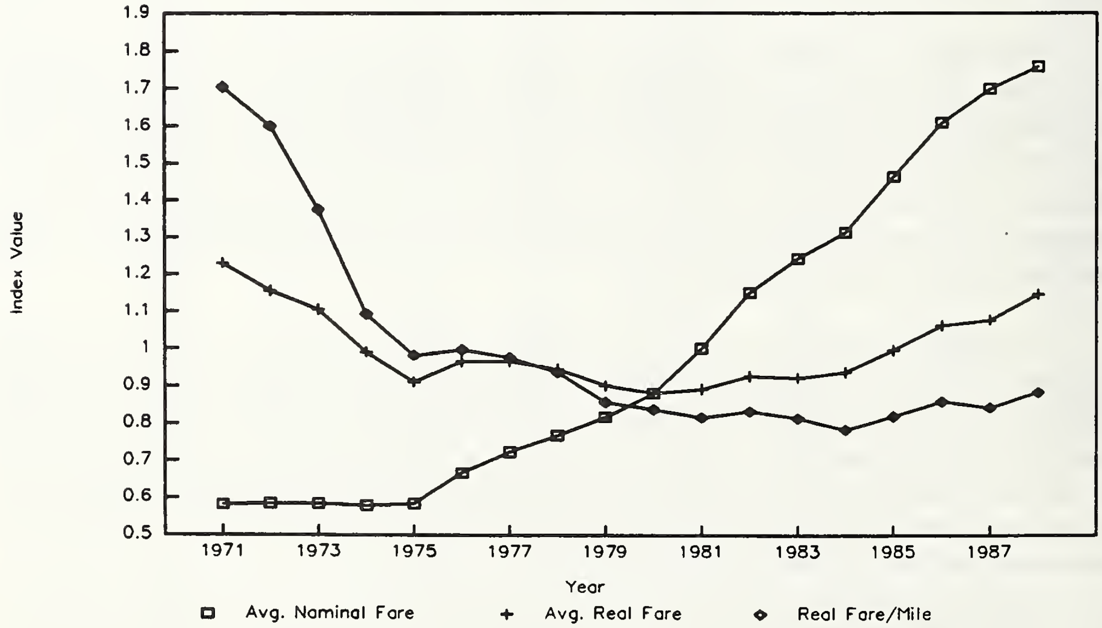
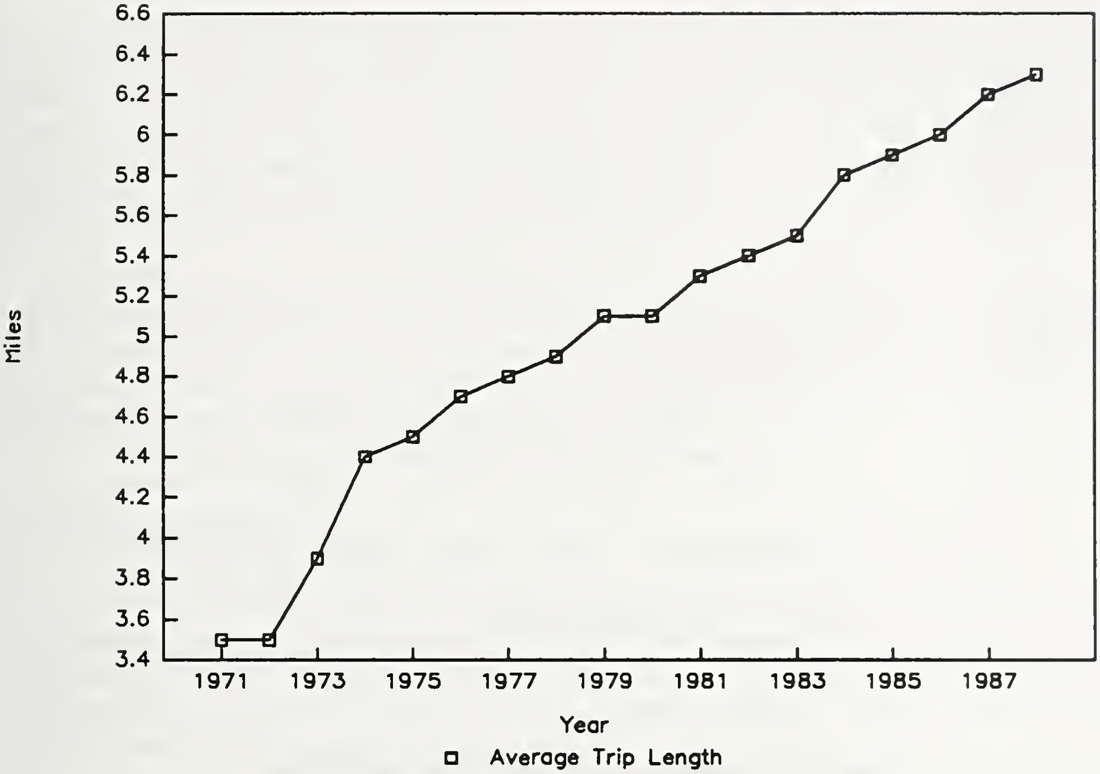


Figure 5-8. Average Peak Period Trip Length (1971-1988)



OC Transpo's aggressive service expansions, both the provision of service to previously unserved areas and increases in frequency on established routes, in excess of ridership growth, had the inevitable effect of worsening the authority's farebox recovery ratio (the ratio of system revenues to operating costs). As Figure 5-9 reveals, however, most of the decline occurred during OC Transpo's first four years of operation, when its farebox recovery ratio plummeted from 1.07 in 1971 to .57 in 1975; the ratio then increased to .63 in 1977, and has tended to drift slowly downward since 1977. In spite of its strenuous efforts to stop the decline, OC Transpo's farebox recovery ratio was .57 in 1988 .

The slow decline in OC Transpo's farebox recovery ratio since 1977 occurred in spite of efforts by the authority to reverse the downward trend by raising real fares and increasing system productivity. These efforts have been particularly pronounced since 1980; Figure 5-10 reveals that OC Transpo achieved rapid increases in passenger miles per bus service mile between 1980 and 1988. OC Transpo achieved these increases by using larger buses, by route consolidation and, since 1983, through speed improvements provided by its steadily expanding busway system. The resulting productivity gains were not free, however, since they were accompanied by fairly large increases in transfer rates (transfers per revenue rider) which appear to have adversely affected ridership.

OC Transpo officials in discussing the advantages of their exclusive busway system, relative to an LRT system, emphasize that their busway system requires many fewer transfers than

Figure 5-9. Ratio of Farebox Revenues to Operating Costs (1971-1988)

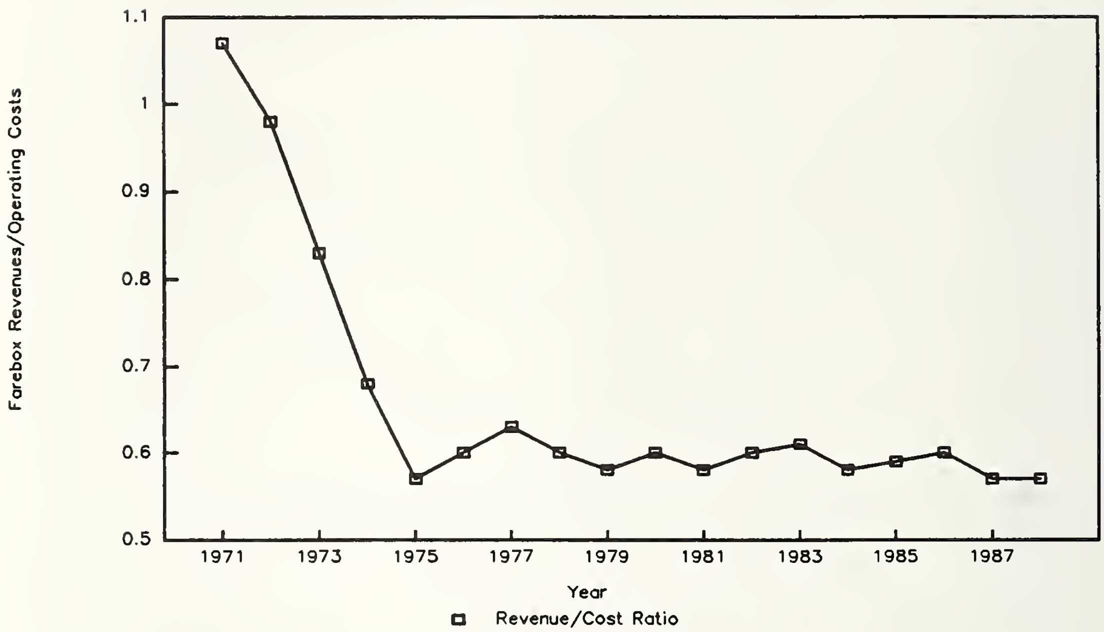
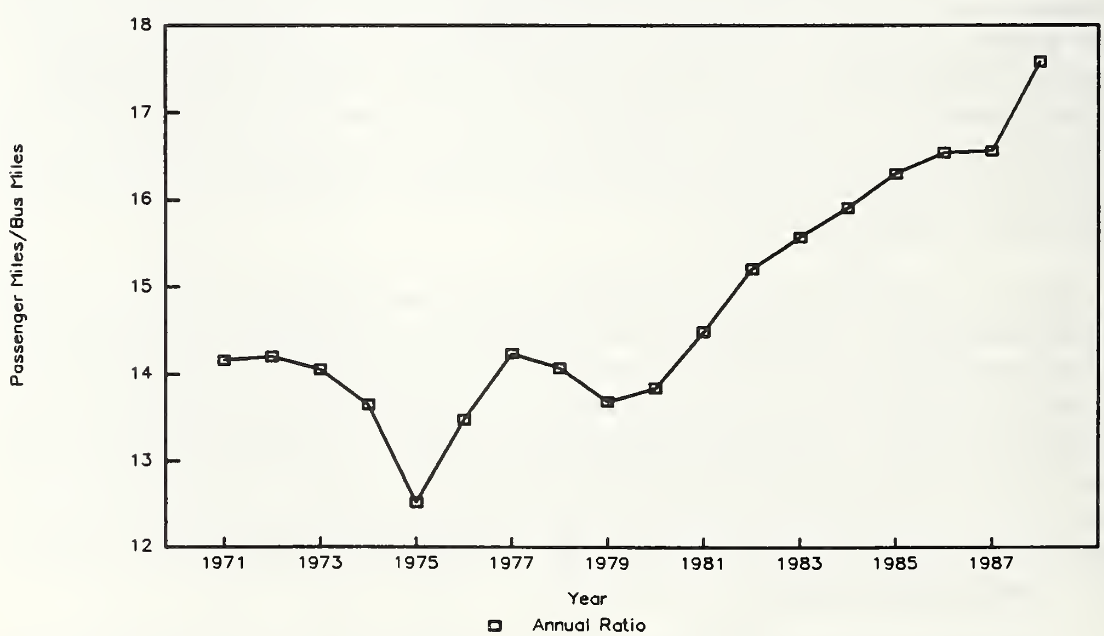


Figure 5-10. Passenger Miles Per Bus Mile By Year (1971-1988)



a comparable LRT system. At the same time, it seems relatively clear that system changes associated with efforts to increase productivity caused transfer rates to increase and these increased transfer rates adversely affected ridership.*

As can be seen from Figure 5-11, OC Transpo transfer rates began to increase in 1981 and the rate of increase accelerated after 1986. Many of these additional transfers may have been voluntary in the sense that riders chose higher frequency routes and faster routes requiring transfers in preference to less frequent service and slower routes that did not require transfers.** At the same time, it seems likely that the system changes associated with efforts to increase system productivity and the implementation of busway services altered the choice set as well.

In spite of the recent decline in ridership and the somewhat disturbing increase in transfer rates, OC Transpo's overall performance remains extremely strong. At a time (mid-1980's) when most transit operators in North America experienced significant declines in ridership and a serious deterioration in financial performance, OC Transpo was able to maintain ridership and maintain a relatively high farebox recovery ratio.**

Operating Cost Savings

In February 1986, after over two full years of busway operating experience, OC Transpo completed an analysis of the operating and capital cost savings from busway operations.*** The study made the simplifying assumption that ridership and system revenues would have been the same without the busways, and then estimated how much it would have cost to provide the same level of service without the busways.****

Comparing hypothetical "without busway" to actual operating costs, OC Transpo (1986) found that the cumulative operating and capital cost savings (exclusive of the busway construction costs) from the first 31 km of busways would be $247 million by 1994 (1989 Canadian dollars) or $209 million in 1989 U.S. dollars. As Figure 5-12 indicates, moreover, the net savings arising from the busways increase rapidly after 1988 and reach $44 million (1989 Canadian dollars) per year by 1995, equal $37 million in 1989 U.S. dollars. These savings arise primarily from

* OC Transpo's transfer rate increased from .29 in 1982, the year before the first section of its exclusive busway system opened, to .40 in 1988, an increase of 38 percent. Applying the estimated transfer rate elasticity of -.35, estimated by Kain (1989) using Ottawa ridership data, to the 38 percent increase in OC Transpo's transfer rates between 1982 and 1988 produces a projected 13.3 percent decline in transit ridership (linked trips). As we indicate previously, Bonsall (1989b, 1990) disputes this interpretation. He contends that the transfers were a voluntary shift to the fast and frequent transitway services, and that other factors were responsible for the declines, particularly the continuing suburbanization.

** A telephone interview survey of 1,200 Ottawa-Carleton residents by the Carleton University School of Journalism carried out in April 1988 found that 69.9 percent of frequent riders agreed or strongly agreed with the statement, "transfers were generally convenient." Only 12.7 percent disagreed and 9.1 percent had no opinion. The findings for infrequent riders were: strongly agree, 2.6 percent; agree, 72.5 percent; disagree, 10.7 percent and don't know, 11.3 percent. At the same time, 8.8 percent of frequent riders strongly agreed and 27.7 percent agreed that "route changes were too frequent." The fractions for infrequent riders were 10.0 percent and 31.2 percent respectively (OC Transpo, 1988a, p. 15).

** Ottawa's transit ridership during the period, for example, compares favorably with Calgary, where between 1982 and 1987, despite increasing population, annual transit ridership declined by over 14 percent, from 53.8 million to 46 million.

*** This section draws extensively from OC Transpo (1986).

**** Given the improved levels of service accompanying the construction of busways, it might have been appropriate in the analysis to assume higher levels of ridership with busways.

Figure 5-11. Annual Transfer Rates: OC Transpo (1972-1987)

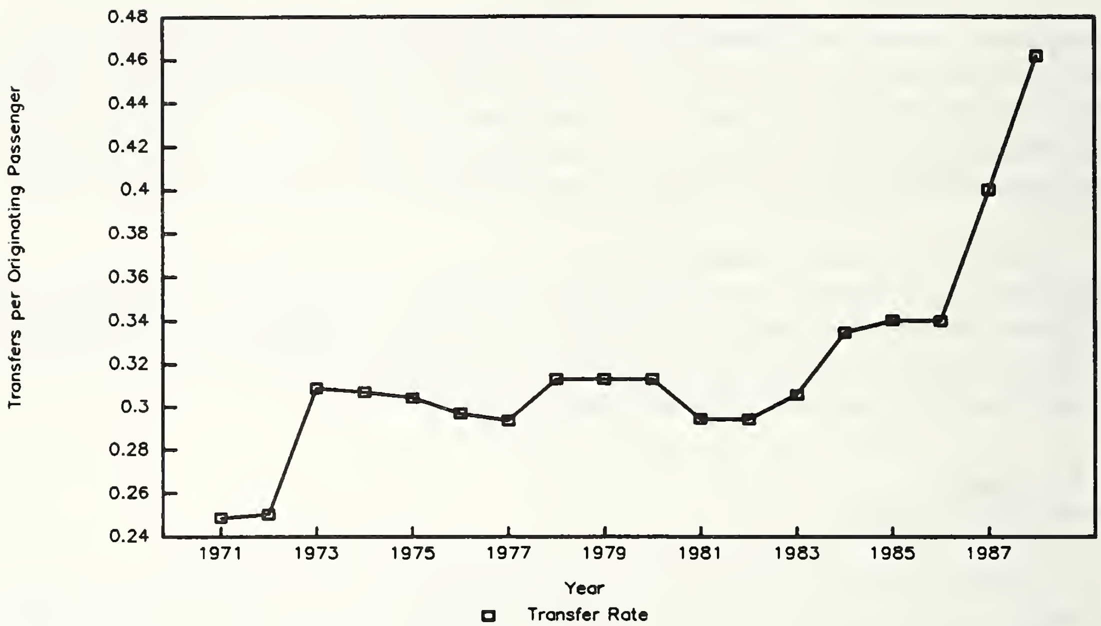
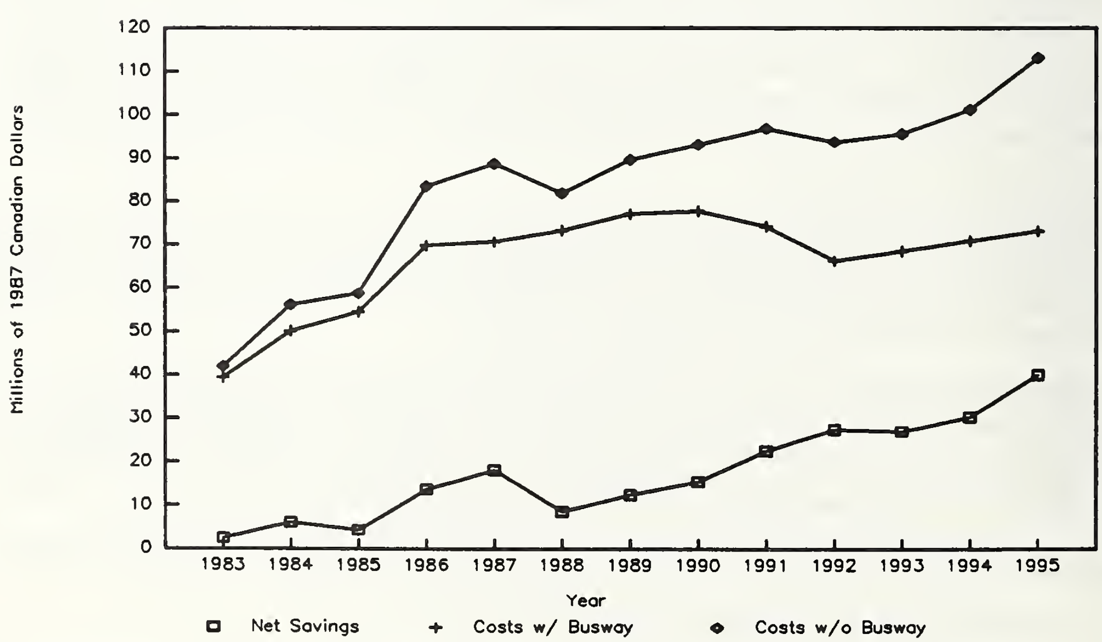


Figure 5-12. Net Savings from Busway (1983-1995)



more efficient use of the bus fleet. In particular, higher operating speeds made possible by the busways translate into a requirement for 220 fewer standard and 40 fewer articulated buses. A smaller bus fleet, of course, means lower capital costs. In addition, OC Transpo will be able to avoid building a new garage that would have been required to maintain the larger "without busway" fleet. Of course, higher busway speeds also provided OC Transpo's passengers with significant time savings and other benefits.

OC Transpo's estimated $209 million (1989 U.S. dollars) cumulative operating cost savings (including depreciation) by 1994 are substantially less than the estimated $373 million (1989 U.S. dollars) capital costs of the first stage busways, even without discounting these future savings to obtain a net present value estimate. Of course, the system will have a substantial asset value after the end of 1994 as well.

A more appropriate calculation would be to calculate the net present value of operating and capital cost savings over the system's useful life. Still another approach would be to use the 10 percent rule-of-thumb recommended by UMTA for assessing federal funded transit projects in the United States. Using this convention, a $373 million capital investment has an annualized capital cost of $37 million per year, which incidentally is equal to OC Transpo's projected annual operating cost savings in 1995 (in 1989 U.S. dollars). Annual operating and capital cost savings from the busway are smaller for the 10 years before 1995, but they appear to be growing rapidly. These calculations indicate that the operating and capital cost savings provided by Ottawa's busways come very close to justifying the investment by themselves. It would be hard to find another rapid transit investment anywhere in the world that could make that claim.

Beyond the cost savings described above, Bonsall also claims that Ottawa's busways have induced development around the system's stations and that this trend is likely to continue. He observes:

> Much has been written about the development impacts of rapid rail transit. Preliminary indications in Ottawa-Carleton show that a similar relationship exist for busway systems. High rise construction is already occurring at some stations and an integrated shopping center/Transitway station has been built. In total, $1 billion in new construction is already underway or in the final planning stations around the Transitway stations. This is four times what has been spent on the Transitway to date (Bonsall, 1989a, p. 11).

Although such claims are difficult to evaluate, even a brief visit to Ottawa provides support for Bonsall's claim that extensive new high density development is occurring around several busway stations; the joint busway/shopping center development in St. Laurent is particularly impressive. The development around busway stations in Ottawa suggests that busways may have "urban form shaping" features similar to those that are often claimed for light and heavy rail systems. Ottawa's experience strongly supports the common sense conclusions that the levels of ridership and station volumes are what matter in encouraging higher density development around stations, and that the particular line-haul technology has little, if any, independent effect.

Planning the Ottawa Busway

The Ottawa-Carleton metropolitan region, with a population of 600,000, consists of 11 rural and urban municipalities of which Ottawa, Canada's capital and the seat of Ontario's provincial government, is by far the largest. The Ottawa-Carleton regional government was formed in 1969, in response to the rapid suburbanization that was occurring immediately outside the boundaries of the City of Ottawa.*

Ottawa-Carleton's "two-tier" metropolitan government is fairly typical of the arrangements that have been implemented in Canadian metropolitan areas. Like analogous structures in the United States, the upper tier (the Regional Council) performs various region-wide functions, such as sewer and water and transportation, while the lower tier (municipal governments) provides services of more local concern. The Regional Council's responsibilities for urban transportation include the development and implementation of a regional transportation plan; planning and building the arterial road system; and, through the regional transit authority (OC Transpo), the provision of public transit services.

Transit planning conforms to the region's overall transportation plan, which unequivocally states, the Ottawa-Carleton government has given "precedence to public transit over all forms of road construction or road widening" (Bonsall, 1987, p. 3). Since the early 1970's, the regional government's policy has been to rely on public transit to provide most of the growth in transport capacity required to meet the needs of the region's growing population.

In the early 1970's OC Transpo, as the transit operating agency, began to carry out the regional government's transportation policies. OC Transpo adopted a two-phase approach. First, it made, and continues to make, every effort to increase the efficiency and use of the region's existing bus system. This included efforts to spread out peak period travel and the implementation of various bus priority measures. The single most effective measure was probably OC Transpo's success in persuading the federal government and several other large downtown employers to adopt flexible working hours, at the same time it improved off-peak bus frequencies and made other system improvements that encouraged off-peak commuting.

As discussed previously, OC Transpo's efforts produced a nearly 30 percent increase in ridership between 1977 and 1984. Since 1984, system ridership has decreased every year until by 1988 it was only 92 percent of its 1984 level. Bonsall (1989b) identifies substantial increases in real fares and reductions in evening services as the principal factors causing the declines. He also, however, points to changing demographics and the increasing suburbanization of land use as other, and in the long term, more important factors.

The second major task for OC Transpo was the development of a rapid transit plan for the region. The authority began this process in the mid-seventies and completed a technology assessment of alternative rapid transit systems during 1978. In this analysis, the region and OC Transpo's consultants, the Deleuw-Dillon-IBI Group, compared the benefits and costs of compa-

* The City of Ottawa was and still is the largest urban municipality within the region, but during the 1950's and 1960's, significant population growth had begun to occur in the surrounding townships. The Ontario Provincial government believed that a more comprehensive approach to the needs of the region --large enough to encompass the total commuter area-- would be beneficial. Thus a new level of government, between the local municipalities and the Provincial government, with specific jurisdiction in the provision of major services and overall planning was formed by an Act of the Ontario Government.

rable busway and light rail transit systems, for two future population levels, 625,000 and 750,000 (Deleuw-Dillon-IBI, 1978).

The Deleuw-Dillon-IBI study found that anticipated increases in metropolitan population and employment and projected increases in transit ridership justified the development of a rapid transit system for the region. The authors of the study suggested further that the region would be best served by what it termed an outside-in transit development strategy, i.e. one that built rapid transit lines from the outside-in, relying initially on surface street operations in the central area. The consultants and staff thereby rejected the more common strategy of building a costly downtown subway first, before gradually extending the system's length toward suburban area. In the outside-in approach selected by Ottawa's policy-makers, construction of the most expensive part of the system, the downtown segment, is deferred in favor of less costly construction in the corridors leading to the downtown.*

The principal justification for Ottawa's outside-in approach to developing its rapid transit system was that near-term benefit/cost ratios were much higher for the relatively inexpensive outer segments than for the costly CBD links. In addition, forecasts of future transit use indicated that the building of a costly tunnel or other grade-separated facility in downtown could be safely deferred for 20 to 25 years. By adopting the outside-in approach, Ottawa was able to begin by building the three segments of the busway with the largest net benefits, i.e. the congested travel corridors leading to the downtown.

Recent declines in OC Transpo ridership provide further evidence that the authority made the right decision in postponing construction of the expensive central area segment. Unless these trends are reversed, the projected levels of transit ridership may never occur; 1987 could well turn out to have been the maximum ridership year. Still, as John Bonsall (1990) points out, the argument for building the central area bus tunnel is based more on peak period use of the central area streets than on total daily ridership, and he contends that peak period transit ridership has not declined. Bonsall adds that with the current at-grade operations in the central area, the system experiences a major disruption, entailing a 10-15 minute delay, about 5 percent of the time (approximately once a month). These incidents not only increase transit times for CBD commuters, but they also disrupt schedules and increase transit times for other users of the system.

After the Deleuw et al. study (1978) had made a prima facie case for some form of a rapid transit system and for the outside-in strategy, OC Transpo initiated the second stage rapid transit system appraisal, a detailed evaluation of each of the five major travel corridors, the Southeast, West, Central, Southeast and East corridors identified in the region's transportation plan.

OC Transpo's selection of an outside-in approach to system development strongly influenced the third stage of the evaluation process, the choice of a specific technology. The outside-in strategy limited the technologies considered to ones that could operate, at least initially,

* As we discuss in Chapters 9 and 10, Houston followed a similar strategy in the development of its innovative transitway system. The outside-in strategy was effective in Houston because the per mile cost of Houston's transitways were quite low and there was very little congestion inside the beltway.

at-grade on downtown streets. This effectively narrowed the field to a busway or a light rail system.

Busways vs. LRT in Ottawa-Carleton*

OC Transpo completed two technology assessments. The first, carried out by Deleuw-Dillon-IBI Group (1978), compared total system costs and benefits for busway and light rail systems with comparable coverage. For its 1978 study, the Deleuw-Dillon-IBI (DDI) Group carried out detailed assessments of the four rapid transit alternatives listed below:

1. A bus transitway (busway) system using standard buses. Busway operations included semi-express and local stopping services and were designed to minimize transfers by combining feeder and linehaul routes whenever possible.

2. A bus transitway system with the same characteristics as (1), except that articulated buses are used wherever there was sufficient projected use to maintain a minimum 10 minute peak period headway.

3. An LRT system with standard bus feeder routes.

4. An LRT system identical to (3), except that articulated buses are used rather than standard buses whenever demand was sufficient to use them without reducing peak period headways below 10 minutes.

Each of the four alternatives were compared along five dimensions: (1) capital and operating costs, (2) level of service (each had to be able to accommodate at least 15,000 peak hour, peak direction riders), (3) the potential for staging, (4) flexibility, and (5) environmental impact. In addition each alternative had to satisfy one absolute constraint; it had to be able to operate at-grade within the downtown area with "acceptable" impacts on the downtown street system.

All four alternatives assumed staging in conformance with the previously selected outside-in development strategy. In each case, a first stage system was defined which provided mostly grade-separated facilities outside of downtown; in downtown the first-stage systems assumed at-grade operations on existing surface streets. The consultants assumed, further, that total system ridership would be identical for all four alternatives, even though the busway and light rail alternatives were recognized as having somewhat different service characteristics.

In their assessment of the service characteristics of the competing systems, the consultants found the busway alternatives required users to make fewer transfers and incur less waiting time, while the LRT alternatives provided a more comfortable ride. In spite of these and other differences, the consultants took the position that likely differences in ridership between the competing systems were too small to predict with any degree of accuracy. In particular, they argued that the prediction errors in forecasting future system ridership for all four systems were most likely larger than any measurable differences due to variations in service characteristics.

* The discussion in this section relies heavily on "Ottawa-Carleton Rapid Transit Development Programme" (Deleuw-Dillon-IBI Group, 1978).

Of the several criteria considered, OC Transpo gave the heaviest weight to total annual system cost. As Table 5-4 indicates, the total annual cost of each of the four alternatives was obtained by adding total annual operating costs to the annualized costs of each component of capital cost.

The consultants used fairly standard procedures in estimating capital and operating costs. Each capital item was depreciated using conventional assumptions about the expected life of each component and a 10 percent interest rate was used in calculating the annual economic cost of capital used in building the system. Rounding the figures, the resulting estimates of total annual cost (1989 U.S. dollars) for the four alternatives were:

1. Busway: Standard Bus- $126 million

2. Busway: Standard plus Articulated Bus- $117 million

3. LRT: Standard Bus Feeder and Local Service- $140 million

4. LRT: Standard and Articulated Feeder and Local Bus Service- $134 million

Operating Costs

While the finding that the busway alternatives would have lower total costs was not particularly surprising, a second conclusion, that the best busway would have slightly lower operating costs than the best LRT alternative, was unexpected. The conventional wisdom has been that LRT-based transit systems have much lower operating costs than all-bus systems, even those operating on exclusive busways.

The widely held view that LRT systems have lower operating costs comes from the observation that LRT systems can be operated as multiple unit trains with a single driver. Since direct operating labor costs comprise as much as 75 percent of total operating costs for urban bus systems, the fact that a single driver can operate a train with several cars, is widely thought to insure a significant operating cost advantage for LRT technology. In the Ottawa alternatives analysis, standard buses were assumed to have a capacity of 54 persons, less than half the capacity of LRVs, which had an assumed capacity of 117. Articulated buses were assumed to have a capacity of 102, 87 percent of the capacity of LRVs.

The Ottawa alternatives analysis did not support the conventional wisdom about operating costs. As the data in Table 5-4 indicate, the Ottawa comparisons did find that an LRT system with standard feeder buses would have lower operating costs than a busway system with standard buses. The same study determined, however, that if articulated buses were used, when justified by demand, a busway system would be the lowest total and operating cost alternative. An LRT system that used articulated feeders, when justified by demand, had the second lowest total and operating cost. We will refer to these two least cost alternatives as the Best Busway (BB) and Best LRT (BLRT) systems in future discussions of these alternatives.

Table 5–4. Total Annual Cost Comparison – 625,000 Population Level (Millions of 1989 US Dollars)

	Busway		Light Rail	
Costs	Standard Bus	Articulated Bus	Standard Bus	Articulated Bus
Annual Operating Costs	$93.93	$83.67	$91.83	$84.42
% of Low Cost Alternative	112%	100%	110%	101%
Annual Capital Costs	$32.11	$32.95	$48.73	$49.54
% of Low Cost Alternative	97%	100%	148%	150%
Total Costs	$126.04	$116.62	$140.56	$133.97
% of Low Cost Alternative	108%	100%	121%	115%

Note: Busway Articulated Bus is the low cost alternative.
Source: "Ottawa–Carleton Transit Development Programme," Deluew–Dillon–IBI Group, September 1978.

According to the data in Table 5-4, at the 625,000 population level, the LRT-Standard Bus Alternative would have annual operating costs that were approximately $2.1 million less than those for the Busway-Standard Bus Alternative; this difference is only 2 percent of the total system operating costs of $92 million (both figures are in 1989 U.S. dollars. Replacing standard buses with articulated buses on routes where the demand justified their use (subject to a 10 minute headway constraint), reduced total operating costs for both Best LRT and Best Busway Alternatives, but the savings were much larger for the busway than for the LRT alternative.

Operating costs for the Best Busway Alternative were 10 percent lower than estimated operating costs for the Busway-Standard Bus Alternative. Lower operating costs were due to the smaller numbers of total vehicles, vehicle miles and vehicle hours required. The size of the required bus fleet was reduced from 766 to 569, and annual vehicle miles and hours were reduced from 34.6 to 29.2 million miles, and 2.49 to 2.2 million hours, respectively.

Not surprisingly, operating cost savings for the Best Busway Alternative were disproportionately concentrated on the fixed guideway component, where savings were in excess of over 22 percent. The number of vehicles required for fixed guideway operations were reduced from 137 to 75 and the number of annual on-guideway vehicle miles and vehicle hours were reduced from 6.9 million miles to 4.8 million miles and from 330 to 240 thousand hours respectively with the selective use of articulated buses.

Savings from using articulated buses were greater for the busway than the LRT system; the use of articulated buses reduced total operating costs for the busway alternative by $10.3 million (1989 U.S. dollars), as contrasted to only $7.4 million for the LRT Alternative. Thus, the Best Busway Alternative had the lowest operating costs of all four alternatives.

The lower operating costs of the Best Busway relative to the Best LRT Alternative, $83.7 versus $89.4 million (1989 U.S. dollars), primarily reflects the fact that busway alternatives are

able to achieve a better matching of demand to capacity.* Additional savings, moreover, can be realized from interlining the buses between busway routes.** The benefits from closer matching of capacity and demand and interlining translate into lower vehicle miles and hour requirements and costs for the busway alternative. The smaller fleet required for the Busway-Articulated Bus Alternative had a good deal to do with the significantly lower costs of this alternative.

Capital Costs

While the conventional wisdom failed in the case of the LRT and busway operating cost comparisons, it held up for capital costs. As Table 5-5 indicates, the 1978 Ottawa alternatives analysis found busway capital costs were significantly lower than those of a comparable LRT system.*** The Busway-Standard Bus Alternative had the lowest capital costs. The capital cost of the Busway-Standard Bus Alternative for a projected 625,000 population level was estimated at $281 million (1989 U.S. dollars), which was approximately 65 percent of the estimated cost of the LRT/Standard Bus Alternative.

The $159 million difference between the Busway-Standard Bus and LRT Standard Bus Alternatives consisted of a $93 million savings for vehicles, $50 million for construction of the right-of-way (which included the costs of track work, electrification and signaling for the LRT that was not required for the busway), and $17 million for garages and maintenance facilities (all figures are in 1989 U.S. dollars).

Table 5–5. Capital Cost Comparisons – 625,000 Population Level (millions of 1989 US dollars)

	Busway		Light Rail	
Cost Areas	Standard Bus	Articulated Bus	Standard Bus	Articulated Bus
Vehicle	$111.81	$119.59	$204.41	$210.81
ROW Construction	$140.16	$140.16	$190.25	$190.25
Garages	$28.76	$27.40	$45.53	$45.53
Total	$280.72	$287.15	$440.19	$446.59

Source: "Ottawa–Carleton Transit Development Programme," Deleuw–Dillon–IBI Group, September 1978.

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* Passenger demand in most of the corridors varies substantially by distance from the downtown. With an LRT operation, the opportunity to short turn trains is virtually non-existent so that, except in the central area, LRV capacity tends to exceed demand. In the case of a busway system, the use of many different bus routes provides more opportunities to adjust the overall system capacity to more closely match demand.

** Interlining routes occurs when radial routes continue through the center rather than turn around. The extent of interlining savings are directly proportional to the number of trips that would benefit from interlining. With a busway system, the bulk of the express services travel in and out of the downtown and produce significant interlining opportunities. With a rail system, on the other hand, the are fewer opportunities to interline because the number of trips between downtown stations are much greater than those between downtown and any one suburban area. The lack of flexibility inherent in LRT system makes interlining more difficult than for buses which can leave the fixed guideway at many different points.

*** Capital costs included the cost of vehicles, construction of the right-of-way (including stations) and vehicle maintenance facilities.

The selective replacement of standard buses with articulated buses increased the capital outlay for buses by $8 million and $6 million (1989 U.S. dollars) for the busway and LRT alternatives respectively. All other costs remained virtually unchanged. The Best Busway Alternative therefore had an estimated capital cost of $281 million (1989 U.S. dollars), a figure that was significantly less than the cost of either of the LRT alternatives.

The Best Busway Alternative also had the lowest total cost. This result is hardly surprising since it had the lowest operating costs of any of the four alternatives considered and substantially lower capital costs than either of the LRT alternatives. Even though operating costs of the Busway-Standard Bus Alternative were greater than those for either of the LRT alternatives, it had the second lowest total cost because of its substantially lower capital costs.

While total annual costs was the primary criteria used by Ottawa decision makers in selecting the rapid transit technology in Ottawa, they considered other factors as well. These are discussed below.

<u>Level-of-service comparisons</u> also favored the busway alternatives because the busways better served the travel patterns of the residents of the low density suburban development that characterizes most of the Ottawa-Carleton region. Even though there are pockets of high-rise development, densities in most parts of the region are such that few passengers would be able to reach the LRT lines or busways by walking. A busway system in which the same vehicle can often provide both feeder and rapid transit services requires fewer transfers and thus provides a higher level of service for most transit riders.

In the opinion of OC Transpo and its consultants, the benefits of fewer transfers provided by the busway were more important that the frequently cited benefit of a smoother ride attributed to the LRT system. The residents of Ottawa, however, appear to have an even greater aversion to transferring than those in most other cities. Bonsall (1990) points to the high proportion of "choice" riders using the OC Transpo system as an explanation for what at first appears to be an unusually "great aversion" by its users to transfers. OC Transpo plans to add additional no-transfer, express services in an effort to remain competitive with the private auto for the commuting trips of these "choice" riders.

OC Transpo's consultants offer the following overall assessment of level of service considerations, "The LRT will have a higher proportion of total passengers requiring at least one transfer, will have somewhat higher ride quality and lower interior noise, and will require a higher proportion of total passengers to stand during peak periods. Considering all of these level of service factors, it is the opinion of the study team that the bus alternatives are somewhat better than the LRT alternatives" (Deleuw, <u>et al</u>., 1978, p. 35).

A 1978 survey of OC Transpo users suggested the increase in transfers required by the LRT would have the same adverse effect on ridership as more than doubling the fare.* One explanation why Ottawa residents have such a strong aversion to transferring may be the fact that

* If the estimated transfer rate elasticity of -.35, obtained by Kain (1989) for Ottawa, is correct, and it should be emphasized that this is a very big assumption, it implies that a one percent increase in the transfer rate would decrease transit ridership (linked trips) by about .35 percent. The transfer rate on OC Transpo's buses increased 38 percent between 1982 and 1988. Given the fixed guideway of an LRT system, it is certain that the increase in transfer rates associated with a LRT system would have been even greater than the 38 percent related to service changes on the Ottawa busway.

transit trip lengths were quite short, averaging only 5.3 miles in 1978. As a result, transfers cause large percentage increases in trip times. The inclement weather conditions which prevail for a considerable portion of the year are very likely another reason why Ottawa residents feel so strongly about transferring.

Staging. OC Transpo also concluded that a busway-based rapid transit system would be superior to light rail in terms of staging. A busway system provides significantly greater flexibility in staging than an LRT system because buses can operate on both the exclusive fixed guideway and on surface streets, permitting a busway to be built and used in discontinuous segments. In contrast to LRT systems, short busway sections that bypass points of heavy congestion can be built and used before the entire system is completed.

Environmental Impacts. OC Transpo's consultants determined that the LRT alternatives would have fewer adverse environmental impacts than the busway alternatives. LRT was projected to have lower levels of air pollution, lower noise levels, and less vehicle related negative visual impact. At the same time, the consultants also pointed out that the LRT's overhead electrical supply system would have a fairly serious visual impact, particularly in downtown. In summary, while OC Transpo and other Ottawa policy makers concluded that an LRT-based transit system would have a lower overall environmental impact, they also determined that the environmental impact of a busway would be modest and that both technologies were environmentally acceptable.

Re-examination of LRT and Busway Alternatives

In May 1981, the executive committee of the regional municipality of Ottawa-Carleton asked for an updated report on the relative costs and benefits of LRT and busways for Ottawa. The motivation for this new look was the opportunity to learn from Edmonton's and Calgary's experience in operating their new LRT systems.

The 1981 study obtained revised estimates of the capital, operating, and total annual cost estimates for the two lowest cost alternatives considered in the 1978 study, i.e. LRT/Articulated Bus and Busway/Articulated Bus (OC Transpo, 1981). These updated estimates used actual busway construction cost data for Ottawa plus the latest LRT construction and operating cost estimates obtained from Calgary and Edmonton, which had both recently begun operating LRT systems, Calgary in 1980 and Edmonton in 1978. The 1981 comparative cost study also incorporated design changes in Ottawa's rapid transit network, particularly the decision to extend rapid transit service to the eastern corridor.

The 1981 study confirmed, and indeed extended, the findings of the earlier (1978) alternatives analysis. It found, as shown in Table 5-6, that the total annual cost of the busway would be only 70 percent as large as for an equivalent LRT system. This compares to a figure of 87 percent from the earlier (1978) study.

The 1981 study estimated that the capital cost of Best LRT would be 50 percent greater than the Best Busway Alternative, $786 compared to $537 million (1989 Canadian dollars), or $664 versus $453 million in constant 1989 U.S. dollars. This difference was very similar to the estimates in the 1978 analysis which found that the capital costs of the Best LRT option would be

Table 5–6. 1981 Total Annual Cost Comparison – 625,000 Population Level (millions of 1989 US dollars)

Costs	Busway Alternative	Light Rail Alternative	Best Bus/ Best Rail
Annual Operating	$87.4	$106.9	81.8%
Annual Capital			
Vehicle Related	$18.6	$26.1	71.2%
ROW	$12.8	$17.5	73.3%
Total	$118.8	$150.5	79.0%

Source: Regional Municipality of Ottawa Carleton, Inter–departmental Correspondence, December 1981.

55 percent higher than capital costs of Best Busway Alternative. Detailed capital cost estimates, shown in Table 5-7, reveal that the $209.6 million difference between Best Busway and Best LRT is made up of $129.3 million for vehicles, yards and shops, and $80.3 million for right-of-way construction, all figures are in 1989 U.S. dollars.*

As in the initial alternatives analysis, the Best Busway Alternative had lower operating costs than the Best LRT system. As the data in Table 5-8 reveal, the estimated operating costs of the Best LRT Alternative were 23 percent greater than the Best Busway system, $129 compared to $105 million (1989 Canadian dollars), or $107 versus $87 million in 1989 U.S. dollars.* The updated operating cost estimates, which were based on actual LRT operating costs of the recently completed Edmonton and Calgary systems, and actual bus operating costs in Ottawa, significantly increased the busway operating cost advantages. The 1981 study found that operating costs for the busway system would be only 80 percent as large as operating costs for a comparable LRT system; the 1978 study, in contrast, estimated that operating costs of the Best Busway would be 99 percent of the Best LRT alternative.

Future System Extensions

Ottawa's actual operating experience with its busway is broadly consistent with the predictions of the two alternatives analyses and confirms the view that a bus-based rapid transit system will be a cost-effective way of meeting Ottawa-Carleton's transit needs for the foreseeable future. It is clear, moreover, that greater use of articulated buses will permit OC Transpo to increase peak hour ridership from its current level of about 9,000 riders per hour in the peak direction to the projected level of 15,000. As a result, it is unlikely that the present peak hour busway volume of 180 buses per hour at the maximum load point will grow to much above 200.

Even though peak hour busway volumes at the maximum load point are not expected to grow by much, Ottawa and OC Transpo officials believe that grade separation of the downtown link will eventually be necessary. Anticipating this eventuality, OC Transpo has been reviewing a

* Significantly, a LRT-based system would require only 86 fewer buses than the busway-based system, in addition to 117 light rail vehicles. A busway-based system would require 382 standard and 310 articulated buses for a total of 692. A LRT-based system would require 374 standard and 234 articulated buses for a total of 608.

Table 5–7. 1981 Best Busway and Best LRT Alternatives Analysis
Capital Cost Estimates (millions of 1989 US dollars)

Item	Best Busway	Best LRT	Difference (LRT–Bus)
Vehicle–Related			
Articulated Buses	$110.6	$83.4	($27.1)
Standard Bus	$62.8	$61.5	($1.3)
LRVs		$141.7	$141.7
Garages	$53.6	$46.0	($7.6)
Yards and Shops		$23.7	$23.7
Subtotal	$227.0	$356.3	$129.3
Busway Construction	$222.8	$303.1	$80.3
Total	$449.8	$659.4	$209.6

Source: OC Transpo. 'Transitway Technology Updated," December 1981

Table 5–8. 1987 Best Busway and Best LRT Alternatives Analysis:
Operating Costs Comparison at 625,000 Population Level
(millions of 1989 US dollars)

Item	Best Busway	Best LRT	Difference (LRT–Busway)
Platform Hours	$54.0	$62.8	$8.8
Kilometrage	$19.0	$25.1	$6.1
Fuel and Power	$12.7	$11.2	($1.5)
Station Maintenance	$0.5	$0.5	$0.0
ROW Maintenance	$1.1	$7.1	$6.0
Total Operating Cost	$87.4	$106.8	$19.4

Source: OC Transpo. 'Transitway Technology Update," Dec. 1981.

recent evaluation of alternative grade separated transitways through downtown completed by Delcan Corporation (1988).

The Delcan Corporation study, which recommends a deep bore downtown transit bus tunnel, considered three alternatives: (a) a shallow bus tunnel, (b) a deep bore bus tunnel, and (c) an elevated busway. The argument for constructing a downtown bus tunnel stresses the benefits to both transit and non-transit users. These benefits consist principally of operating cost savings to the bus system, and travel time savings for both transit users and for non-transit users of central area streets. Thoughts about converting Ottawa's bus rapid transit system to rail have been pushed into the distant future as Ottawa officials are satisfied with their exclusive busways, and do not expect system capacity to be a problem in the foreseeable future.

The Delcan study (1988) mentioned above estimated the present value (PV), the net present value (NPV) and the internal rate of return (IRR) of costs and benefits for the three alternatives in Table 5-9. *Of the three alternatives, the Deep Tunnel yielded the highest NPV and the Shallow Tunnel the smallest. The Deep Tunnel Alternative had a somewhat larger NPV than the Elevated Alternative, $138.3 million in 1989 U.S. dollars versus $131.9 million. The IRR for the Elevated Alternative of 8.6 percent was slightly higher than the 8.4 percent return obtain for the Deep Tunnel. The Delcan study identifies the Deep Tunnel as the preferred alternative.

The deep bore tunnel recommended by Delcan Corporation would actually be twin tunnels, one under each of the one-way streets, Albert and Slater, that currently connect the two segments of the exclusive busway. The tunnels would begin at the existing Campus Station, shown in Figure 5-13. From this point, the twin tunnels would descend as they go north from Campus station, under Laurie and would continue under Daly Avenue through the Rideau Centre development. They would then pass under the Canal and National Arts Centre (N.A.C. and C.N.A. in Figure 5-13) and run under Albert and Slater Streets through the Central Area until they exited through the escarpment west of Bronson Avenue and reached the Lebreton Station at Booth Street.

The twin tunnels will be approximately 25 feet in diameter. The approaches to the deep bore tunnels would be built using open cut and cover techniques. The tunnels will cross as they enter downtown so that the vehicle doors will be on the inner side of the tunnel. This decision permits cross platform transfers and greatly simplifies platform design. At the stations in the Central Area, the tunnel cross section would be widened to approximately 46 feet to accommodate a platform (20 feet), bus lane (13 feet) and a passing lane (11.5 feet).

The proposed downtown bus subway would have four stations which would be built between the two tunnels under the cross streets in the short block between Albert and Slater Streets. The stations would consist of parallel loading platforms 360 feet in length and up to 20 feet wide. While it is anticipated that all buses would stop at all stations, the design provides a

Table 5–9. Results of the Delcan (1988) Benefit/Cost Analysis (millions of 1989 US dollars)

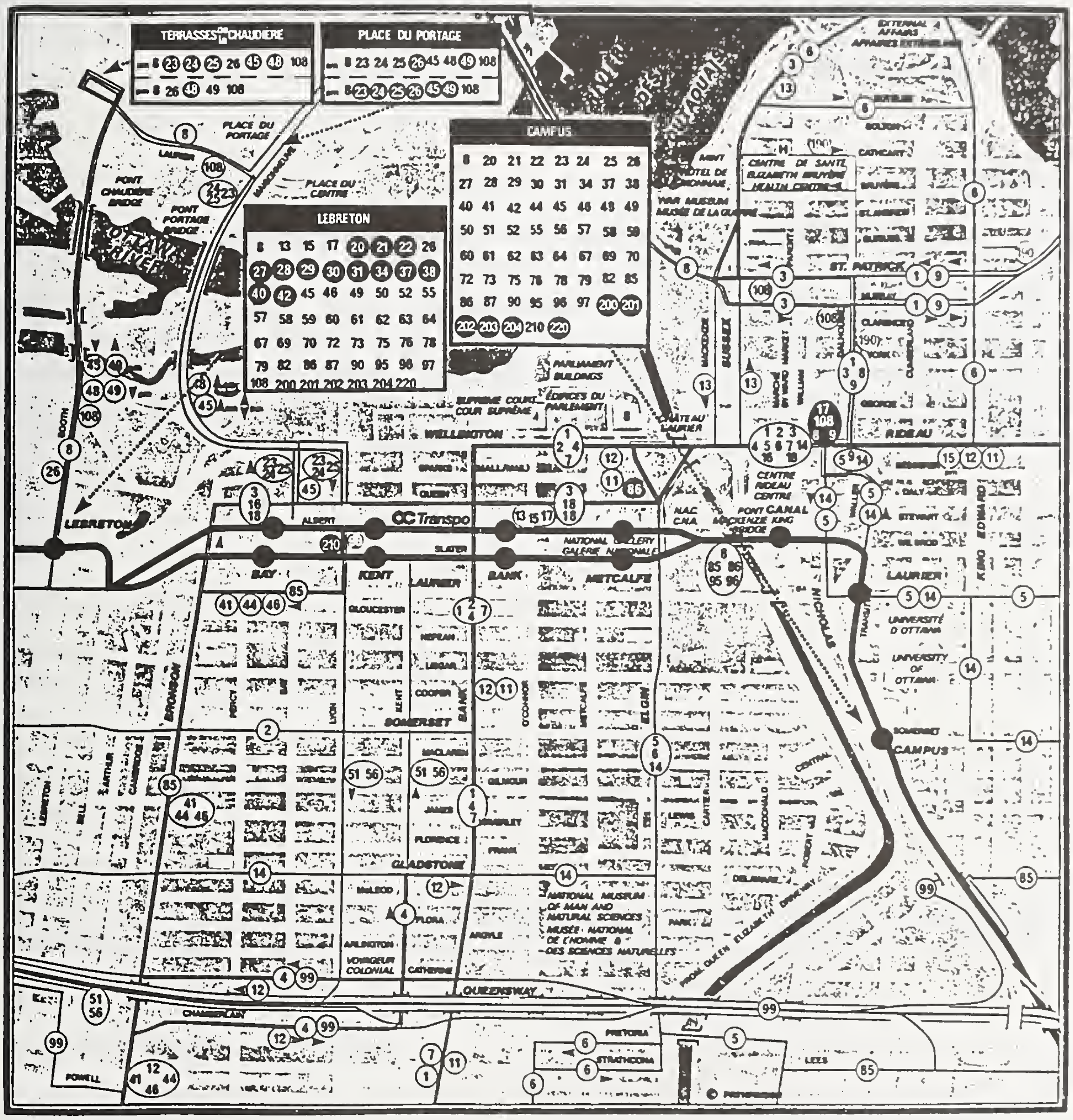
Item	Shallow Tunnel	Deep Tunnel	Elevated
Present Value of Costs	–318.8	–246.0	–218.0
Present Value of Benefits	390.4	384.4	349.9
Net Present Value	71.6	138.3	131.9
Internal Rate of Return	6.0%	8.4%	8.6%

Source: Delcan Corporation, Report on the Feasibility of a Grade Seperated Transitway Through the Central Area of Ottawa," 1988

* We have not been able to evaluate the analysis described here in any detail. We are simply reporting the findings and conclusions of the Delcan Benefit/Cost evaluation at face value.

Figure 5-13.

Ottawa's Proposed Downtown Bus Tunnel



passing lane at each station for emergencies. OC Transpo's consultants estimate the project could be completed in three years with very little disruption to the normal business, shopping, and vehicular activities on the surface.

While projected benefits of the proposed tunnel exceed the project costs by a large margin, the project is quite expensive. OC Transpo and the region have not released precise construction costs estimates for the Deep Tunnel, but they expect its costs will be similar to those of the Seattle Bus Tunnel, which are $372 million in 1989 U.S. dollars. The projected costs of the 1.4 mile long twin tunnels therefore would exceed the total costs of the 14.2 miles of busway completed to date by more than 50 percent; the projected cost of the tunnel, moreover, is similarly about 85 percent as much as the total cost of the entire 19.3 mile First Phase Transitway System, exclusive of the tunnel.

Conclusion

Ottawa's experience with busways demonstrates, as does Pittsburgh's, that bus rapid transit can provide comparable or better kinds of service and carry passenger volumes equal to or larger than those carried by the new rapid rail transit systems in North America, at significantly lower capital and operating costs. When the cost and passenger volumes of the Ottawa busway are compared with those of many of the new rail rapid transit systems built in North America in the last ten years, it becomes clear that busways are an attractive alternative to rail for most situations.

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Chapter 6. Pittsburgh's Experience with Exclusive Busways and Light Rail Transit

Introduction

The Port Authority of Allegheny County (PAAC), through its Port Authority Transit Division (PAT) is the only transit operator in the United States that has built and operated exclusive busways. In addition, PAT recently upgraded part of its ancient streetcar network to modern light rail standards. PAT's experience is thus highly relevant to the questions considered in this report.

Pittsburgh is one of the nation's most important transit markets. In 1980, only six U.S. metropolitan areas had higher journey-to-work transit mode splits than Pittsburgh's 11 percent: New York (28.2 percent), Chicago (16.5), Washington D.C. (16.5), Boston (12.7), Philadelphia (12.5), and San Francisco (11.2) (U.S. Census, 1986). Similarly, only five cities had higher 1980 CBD work trip mode splits than Pittsburgh's 56.4 percent: New York City (80.7 percent), Chicago (74.1 percent), Philadelphia (60.1 percent), Boston (58.4 percent), and San Francisco (56.4 percent) (U.S. Census, 1980a).

While Pittsburgh remains one of the nation's strongest transit markets, ridership has declined in recent decades, both in the aggregate and as a share of total trips. As the data in Table 6-1 show, the transit share of Allegheny County (the SMSA's central county) work trips fell from 21.6 percent in 1960, to 17.7 percent in 1970, and then to 14.8 percent in 1980. The number of transit trips to work, moreover, declined from 133,335 a day in 1960 to 98,231 twenty years later. In addition, as the ridership data in Figure 6-1 indicate, annual boardings declined from oil shock induced peaks of 110 million in 1975 and 1979 and have remained below 90 million since 1983.

At the same time that transit ridership and modal shares have declined, PAT has experienced growing financial difficulties. As Table 6-2 indicates, farebox recovery ratios fell from nearly 90 percent in 1966 to 44 percent in 1986 and the size of the operating deficit increased

Table 6–1. Total Daily and Transit Trips to Work by Allegheny County Workers

	Number			Percentage Change		
Worktrips	**1960**	**1970**	**1980**	**60–70**	**70–80**	**60–80**
Total Daily	617,900	617,200	664,600	–0.1%	7.7%	7.6%
Transit	133,335	109,551	98,231	–17.8%	–10.3%	–26.3%
Percent Transit	21.6%	17.7%	14.8%	–17.7%	–16.7%	–31.5%

Source: U.S. Census, Population and Housing, 1960, 1970, 1980

Figure 6-1. Annual Transit Ridership (Unlinked Trips)

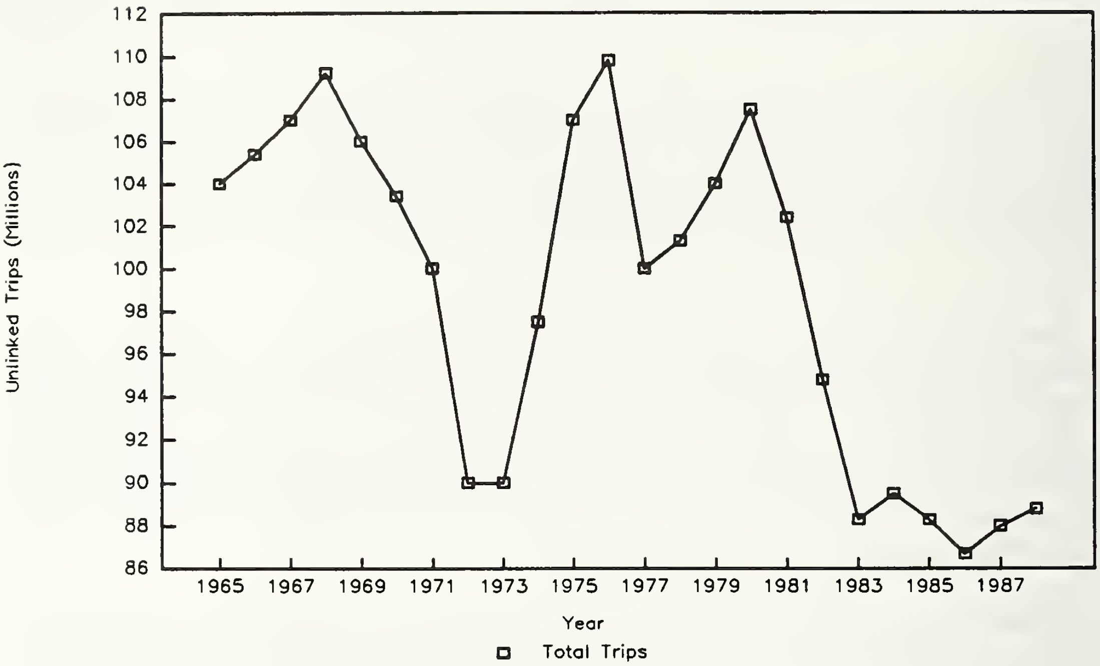

Table 6–2. PAT Fiscal Performance for Selected Years (millions of 1989 dollars)

	1966	1971	1976	1981	1986
Farebox Recovery	89.6%	64.8%	50.8%	49.1%	44.1%
Total Revenue	$103.1	$90.2	$74.5	$77.6	$81.7
Fare Revenue	$99.2	$86.8	$71.5	$75.4	$73.7
Total Expenses	$110.7	$133.9	$140.7	$153.5	$167.0
Operating Deficit	$7.7	$43.7	$66.2	$76.0	$85.3

Source: PAT Annual Reports 1970–1986.

steadily, reaching $85.3 million (1989 dollars) in 1986.* PAT's 1986 revenue shortfall was primarily met with $50.7 million in state funds, $20.7 million of subsidies from Allegheny County, and $10.4 million of federal operating subsidies (all in 1989 dollars).** Unlike Houston, (Chapter

* Pennsylvania state legislation presently (1989) requires a 46 percent farebox recovery for PAT.

** Unless otherwise noted, all dollar amounts are in 1989 dollars. Construction cost amounts are converted into 1989 dollars using the ENR Construction Cost Index. Operating and other costs are indexed using the GNP Implicit Price Deflator.

10), the Bay Area (Chapter 4), and New York City (Chapter 3), PAT has no taxing powers, toll revenues, or other dedicated transit funding sources.

The declines in transit use in Pittsburgh have mirrored the experience of most other U.S. metropolitan areas and reflect changes in the distribution of jobs and residences, rising incomes, and increased levels of car ownership. In Pittsburgh, these general trends have been exacerbated by large declines in the city's population and employment. The Pittsburgh SMSA has the dubious distinction of being the only United States metropolitan area that lost population between 1960 and 1970 and in the following decade its population fell by an additional six percent. Central city (where transit mode splits are highest) population declines have been even larger; Pittsburgh's population fell by 18 percent between 1970 and 1980, and then declined another five percent to 403,000 between 1980 and 1984 (U.S. Census, 1970, 1980b, and 1984).

Declines in transit use would have been even greater had it not been for Pittsburgh's relatively high densities, relatively low levels of auto ownership, and difficult topography. Pittsburgh's urban development and transportation infrastructure are strongly influenced by the region's sharp ridges, narrow river valleys, and steep slopes, which are difficult to climb and in many cases are too costly to develop.

The central city is relatively compact (55 square miles) and continues to have relatively high population and employment densities, even with the large population and job losses since the end of World War II. With 7,270 residents per square mile in 1980, Pittsburgh was the 11th most densely populated U.S. central city, in spite of the fact that gross population density understates Pittsburgh's true density because so much of the land is unsuitable for development.*

Because of its relatively high densities and extensive transit service, Pittsburgh has relatively low levels of auto ownership. High densities and low levels of auto ownership translate into high levels of transit use: Pittsburgh, the nation's nineteenth largest metropolitan area in 1987 (comparing PMSAs and MSAs, U.S. Census, 1988), had the eleventh highest transit ridership in the nation with 88.9 million annual unlinked trips in 1985 (UMTA, 1987).

Since the turn of the century, state, county and city political leaders have passed a variety of legislation and sponsored dozens of studies on how to respond to transit challenges, including the recent declines in transit use and profitability of transit operations. We now consider these proposals.

Proposals and Actions to Improve Transit

Pittsburgh's first transit services began in 1859 with the introduction of horse-cars. Extensive development of electric street railways and inclined railways (required for the steepest slopes) followed in short order, and by the early days of this century, street cars carried 600,000

* This assertion is confirmed by predictions obtained from a regression of central city journey-to-work transit shares on central city gross population densities for the 43 largest central cities with populations of over 350,000 in 1980, which substantially under predict Pittsburgh's transit mode split (Kain, June, 1988). Approximately one fourth of the land in Allegheny County has slopes of 25 percent or greater, and thus is too costly to develop. When Pittsburgh's central city gross population density is recomputed (reducing gross area by 25 percent), it becomes 9,693 making Pittsburgh the 7th densest U.S. city, right behind Washington, D.C..

riders a day over 581 miles of track (PAT, 1989). Pittsburgh's streetcar lines were privately developed, owned and operated, in many cases by real estate developers who built them to stimulate sales of their suburban land holdings. This scheme worked as extensive residential development occurred along the streetcar lines.

Private commuter railroads and street railways continued to provide acceptable levels of transit service until the mid-1950's. Private street railways served all parts of the city and ran between downtown and nearby residential areas and suburban towns. Commuter rail services connected more distant towns to downtown Pittsburgh and many suburban-exurban commuters traveled more than 30 miles to their jobs. By 1955, ridership declines, caused principally by growing competition from private autos, and rising costs led to a drastic curtailment in commuter rail services and within a decade these services had virtually disappeared.

Proposals to replace or complement the region's street railways and commuter rail services with high performance, grade separated rail transit have been put forward since the turn of the century, or even earlier. A 1906 Pittsburgh Subway Company study, for example, recommended the construction of a system of underground railways, consisting of a downtown loop, a radial line to the east, and several other lines extending to the north and across the Allegheny River. It suggested, moreover, that all existing independent streetcar companies should be allowed to use these subway facilities (Parsons, et. al., 1968).

Pittsburgh voters approved a $209 million bond issue (in 1989 dollars, $6 million in 1919 dollars) to build a rail transit system in 1919. The money was never spent, however, because of disagreements as to where the rail lines should be built, and in 1934 the City Council vacated the 1919 rail transit bond issue. Additional studies were made in 1941, 1949, and 1951. All found that congestion was a growing problem, particularly in the downtown, and all proposed building rail transit lines in the eastern and southern corridors.

In 1952 Allegheny County's Board of County Commissioners appointed a transportation committee to study various forms of mass transportation and their potential financial implications. The committee's report released in 1953, urged the county government to acquire the 33 privately-owned bus and streetcar companies (30 bus companies and 3 streetcar companies) and consolidate them into a single regional transit agency (PAT, 1986).

Three years later (1956), the Commonwealth of Pennsylvania's General Assembly enacted legislation authorizing Pittsburgh and several other Pennsylvania metropolitan areas to establish port authorities. The new authorities were given eminent domain powers and were authorized to borrow money and issue bonds for the purposes of planning, acquiring, constructing, and operating port facilities. The legislation did not give the authorities taxing powers or a formula allocation (state subsidies are appropriated annually to individual authorities).*

* Pennsylvania is currently the only urbanized state which has not granted regional transit authorities independent taxing powers. We urge anyone who doubts the effects of greater fiscal stringency and control on transit authority behavior to spend a few days visiting PAT and a few days visiting transit authorities with dedicated revenue sources. Unlike port and bridge authorities in other areas that often have access to surplus revenues from airport landing fees, parking and other concessions, and surplus bridge or tunnel revenues, PAT must do without any of these. Allegheny County, not PAT, owns and operates many of the region's bridges and has never charged tolls.

The Port Authority of Allegheny County (PAAC) was established in 1958.* In the same year, the City of Pittsburgh, Allegheny County, and the Pennsylvania Department of Highways jointly authorized the Pittsburgh Area Transportation Study (PATS) and brought a team of transportation planners from Chicago to carry out a comprehensive transportation study.** The study's final report found that the region's transport infrastructure was badly deficient and recommended building 210 miles of freeway and 16 miles of rail rapid transit. PATS pointed to the unusually small amount of freeway mileage (less than 20 miles for 1.5 million residents) as a major reason for the high levels of congestion on city streets.

The study also argued that Pittsburgh's 33 private transit operators were providing inadequate public transportation because of inefficient route coordination, lack of transfer privileges, and service imbalances. As a way of correcting these deficiencies the study recommended the creation of a publicly owned regional transit authority.

Legislation passed in 1959 expanded the powers of Pennsylvania port authorities to own and operate mass transportation facilities. While the region's private transit operators had a long history of profitable and effective operation, they had begun to experience serious ridership losses, rising costs, declining profits and increasing deficits. Following the recommendations of the transportation committee (1953) and PATS (1958), the Port Authority of Allegheny County (PAT) began to acquire the region's numerous private transit operators. In less than 5 years, PAT had acquired all 33 private transit companies and combined them into a single operating entity.

Shortly thereafter, PAT replaced over 520 miles of street railway (trolley and streetcar) lines with diesel buses, primarily as an economy measure. This process was accelerated by bridge repairs and development projects in the metropolitan area. As the bridges crossing the various rivers were rehabilitated in the late 1950's and early 1960's, the trolley tracks were removed and trolleys using these bridges were replaced by buses (Beim, 1988).*** In 1965, PAT replaced the entire North Side streetcar system with buses, three years later it converted the East End streetcar system to bus transit (Miller, 1976: Voigt, 1989b).****

PAT, however, continued the streetcar operations between downtown and the South Hills (PAT, 1986). The justification for continuing the 23 miles of trolley operations in the South Hills was to maintain an exclusive right of way for transit, after it was determined that the right of ways were too narrow for a new highway (Voigt, 1989a).

In 1964, PAT participated in an UMTA sponsored demonstration project to build and test a 2-mile Skybus system in South Park, south of the Pittsburgh CBD. This project was to test a

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* PAT activities are governed by a 9-member board appointed by the three Allegheny County Commissioners. Board member terms overlap, with three members appointed annually. The board appoints an executive director to manage day-to-day operations.

** PATS core staff included several talented transport planners who worked first in Detroit and then in Chicago. See Kain (1987) for a discussion of the contributions of this remarkable group to transportation planning.

*** For example, in 1959 the former Pittsburgh Railways Company replaced the entire West End service with bus service when the Point Bridge was closed. Bridge rehabilitations would have required expansive new trackwork if trolley lines had not been replaced by bus service.

**** Two major mall projects, one on the North Side and one in the East End, modified street patterns so that trolleys could no longer operate on their original routes and accelerated the conversion from streetcars to buses.

prototype of a new system that had been proposed as a replacement for the South Hills Trolley.* In the following year (May 1965), PAT created an ad hoc Rapid Transit Technical Committee (RTTC), consisting of officials from PAT, the City of Pittsburgh Planning Department, and Carnegie Mellon University, to review and coordinate the growing number of studies, including an ongoing comprehensive study of a county-wide rapid transit system. The RTTC report, completed in December 1967, proposed building a 60-mile rapid transit system. RTTC's recommendations were subsequently adopted by the Southwestern Pennsylvania Regional Planning Commission (SPRPC) as a basis for regional transit planning.

In August 1968, RTTC endorsed three rapid transit facilities as the first phase of a county-wide rapid transit system. The three facilities shown in Figure 6-2, included a Transit Expressway Revenue Line (TERL), using the Skybus technology, that would replace the aging streetcar operations in the South Hills. The RTTC also recommended building two exclusive busways to serve corridors south and east of the CBD, and proposed rehabilitating sections of the South Hills trolley.

The busway proposals emerged because, while there was broad support for building some kind of fixed guideway transit system in the two corridors, rail advocates were unable to agree on the technology to be used; heavy rail, Skybus, and LRT all had strong supporters. The ad hoc committee finally agreed on busways as an interim solution (Crain & Associates, 1985). The plan was called the Early Action Program (EAP) because it was "just the beginning" of a much larger transit program for the region (PAT Annual Report, 1970). The PAT board adopted the EAP in 1969; UMTA awarded PAT $29 million (1989 dollars) for final design and construction of EAP facilities in June 1970; and in September 1971, UMTA provided an additional $176 million (1989 dollars) for final design and to begin construction.

The EAP was stopped in its tracks in early January 1972 when area mayors and one of the three county commissioners filed suit in Common Pleas Court to stop the project. They objected to implementing a new and still largely untested fixed guideway technology, i.e. Skybus, in the South Hills when residents were satisfied with the existing streetcar system. After a 69-day hearing, the court enjoined PAT from making further expenditures on the EAP. PAT appealed the ruling, and in January 1973, the State Supreme Court reversed the Common Pleas Court ruling, holding that PAT had complied with all the legal requirements.

The court's ruling did not quiet the critics, however, particularly in their opposition to the TERL. Their continued opposition led Governor Shapp to announce in April 1974 that the Pennsylvania Department of Transportation (PennDOT) would withhold $90 million (1989 dollars, $38 million in 1974 nominal dollars) in state matching funds until the Port Authority completed additional studies of the South Hills corridor. Although the design of the TERL system was approximately 50 percent complete, the Governor withdrew all state funding in December 1974, and proposed instead that PAT upgrade the existing streetcar system to modern light rail (LRT) standards. The subsequent review process endorsed the earlier decision to build the East and South Busways and ratified the Governor's proposal to convert part of the South Hills streetcar

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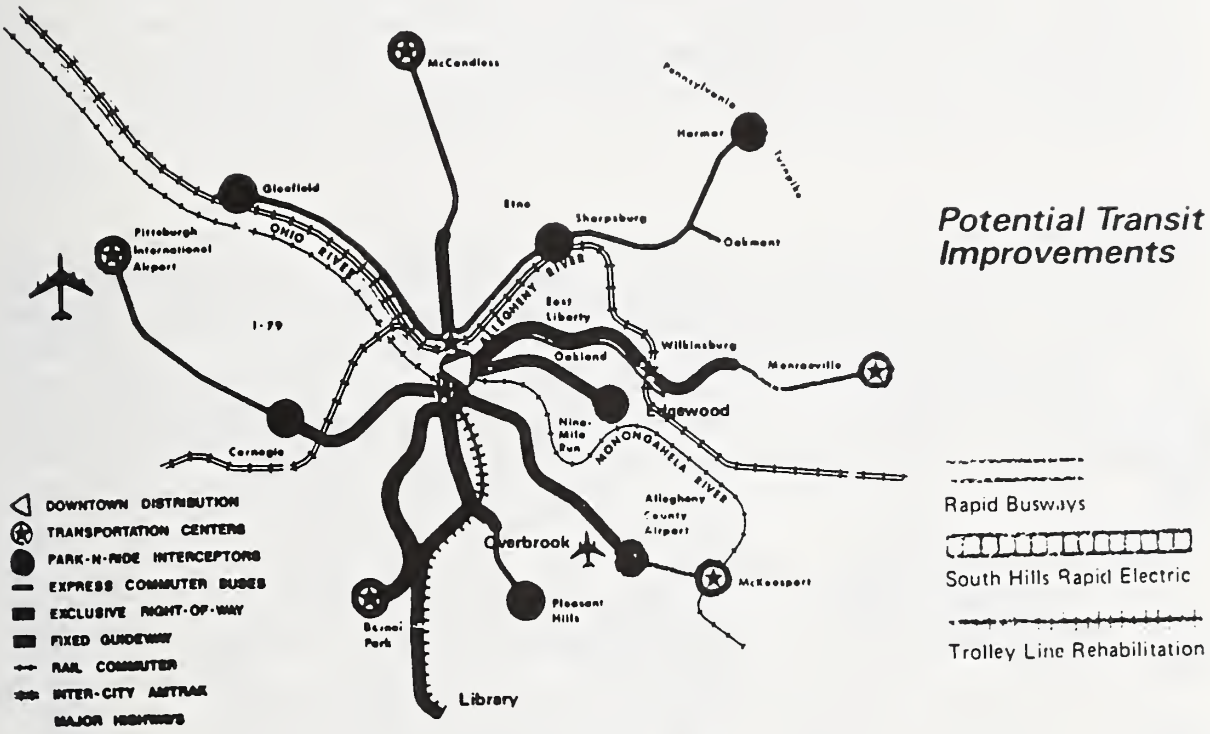
* The Skybus was an electrically-powered, automatically operated, rubber-tired, grade-separated low-to-medium capacity transit system developed by Pittsburgh based Westinghouse Electric Corporation. The Miami and Detroit fixed guideway people mover systems, to be discussed in Chapter 13, are very similar to the proposed Skybus system.

Figure 6-2. The Early Action Program



network to LRT. The discussion that follows considers the design, implementation and operation of these systems starting with the South Busway.

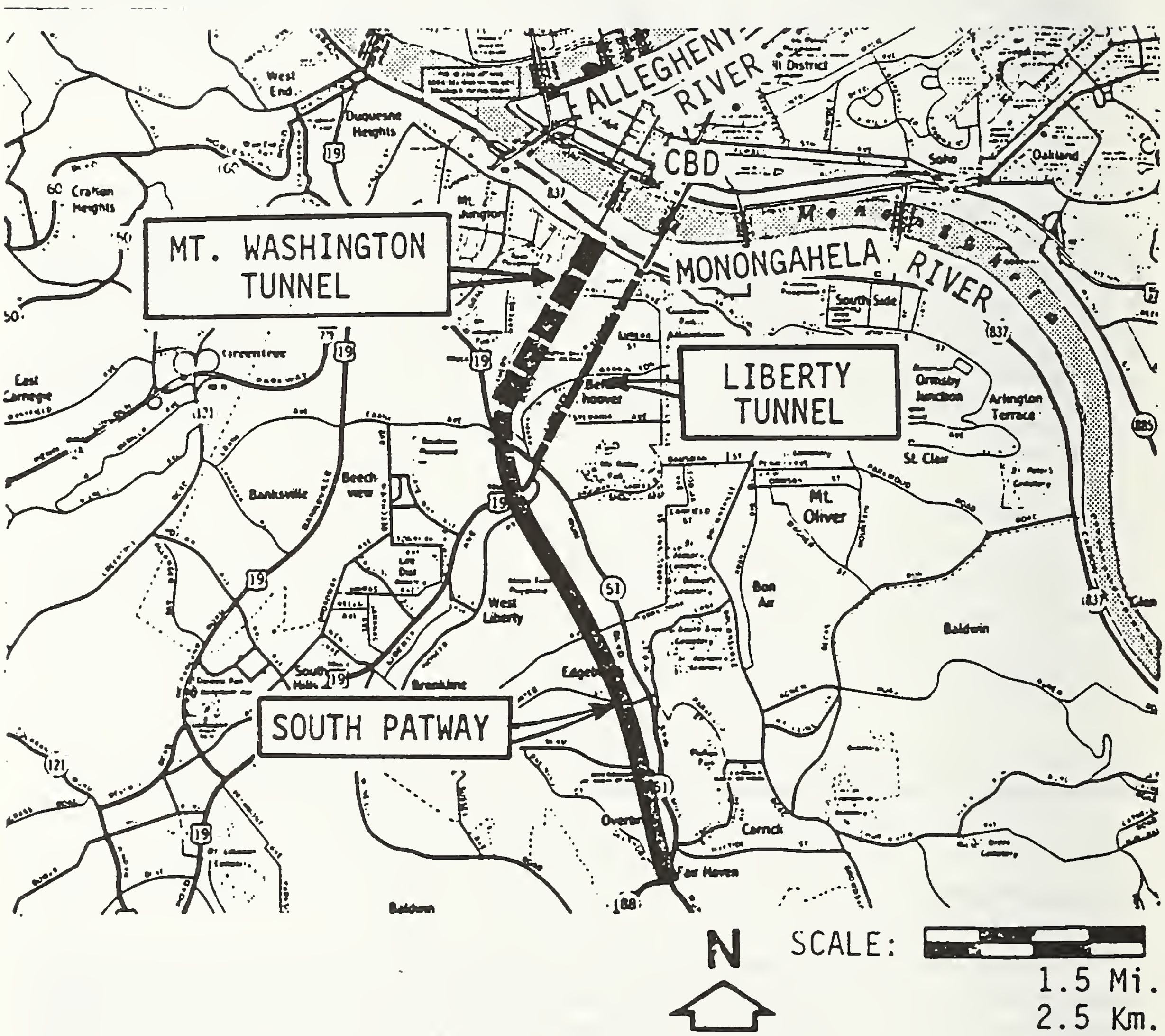
The South Busway

The South Busway, a 3.8 mile, two lane (one lane in each direction) exclusive busway, was opened in 1977. It was built to bypass severe congestion at the Liberty Tunnel, the major roadway link between the Pittsburgh CBD and the South Hills area. To achieve this objective, PAT refurbished the adjacent 3,500 foot long Mt. Washington Trolley Tunnel for use by buses, streetcars and light rail vehicles (LRVs).* In addition, as Figure 6-3 shows, PAT built a new

* New paving and a new ventilation system were provided for the Mt Washington Tunnel so that buses could share the two-lane (one lane in each direction) tunnel with Presidents Conference Committee cars (PCCs) and eventually LRVs.

Figure 6-3.

The South Busway Corridor



bus-only roadway along the Route 51 corridor between Glenbury Street and the Monongahela River.*

The exclusive bus-only portion of the 3.8 mile transitway in the South Hills extends for 1.7 miles and consists of two fourteen foot wide one-way lanes with curbs on each side; while hardly generous, the design provides sufficient width to pass disabled buses. The other 2.1 miles of transitway is shared with trolleys. Operating speeds are set at 40 MPH on the bus-only portion and 30 MPH on the bus/trolley segment. While most buses enter or leave the South Busway at the two ends of the busway, intermediate ramps are provided at West Liberty Avenue, Cadet Street, Warrington Avenue at Haberman Avenue, and Warrington Avenue near Boggs Avenue.

Only 26 percent of the total revenue miles operated by routes using the South Busway are on the transitway; the remaining 74 percent are on city streets in the downtown or on surface streets in residential areas (Voigt, 1989a). Outbound buses using the South Busway collect passengers on downtown surface streets before using the Smithfield Street Bridge to cross the Monongahela River with other traffic. The buses then stop at Station Square station on the south side of the river before entering the Mount Washington Transit Tunnel. After leaving the tunnel, South Busway buses stop at the South Hills Junction station (with trolleys and LRVs) before entering the bus-only segment of the busway.

As the data in Table 6-3 indicate, more than half of all South Busway passengers board one of the 6 West Liberty routes which enter or exit the busway from West Liberty Avenue (Figure 6-4). The remaining 11 busway routes leave the busway at Saw Mill Run Boulevard. In

Table 6–3. Average Daily Ridership by South Busway Routes

Name	Route No.	Time (min)	Scheduled Trips	Riders Per Day	Ridership/ Sched. Trip	Fare ($)
West Liberty Avenue						
Dormont/Pioneer	41A/41G	52	52	2,518	48	.50–1.00
Bower Hill	41B	60	61	3,614	59	.50–1.00
Cedar Blvd.	41C/CB	67	53	1,521	29	.50–1.00
Brookline	41D	33	45	2,028	45	.50–1.00
Subtotal West Liberty			211	9,681	46	
Saw Mill Run Blvd.						
Baldwin Manor	46B/BM	NA	NA	1,494	NA	NA
Curry	46D/E	57	NA	1,644	NA	.50–1.00
Baldwin Highlands	46F/PP	51	NA	1,493	NA	NA
Elizabeth	46G/E/CL	63	NA	2,792	NA	NA
Pleasant Hills	46H/JL	54	NA	913	NA	.50–1.00
Subtotal Saw Mill Run			NA	8,336	NA	
Total South Busway			NA	18,017		

Source: PAT Ridership Analysis, March, 1987

* An early plan by PennDOT was to asphalt the tracks and run buses and trolleys together, however, later designs led to a permanent concrete bus-only roadway.

Figure 6-4.

Pittsburgh Busway: Access Points, Routes and Stations

contrast to the South Hills LRT (discussed subsequently), none of the South Busway stops have park and ride facilities. It would be an exaggeration to refer to South Busway stops as stations; they are more accurately described as platforms reached by stairs or ramps from the local streets.

The terrain in South Hills is quite hilly, particularly in the northern part near the river. Because of steep grades, buses experienced considerable difficulty in operating on local streets before the South Busway was opened. The South Busway was built parallel to N & W railroad tracks on a virtually flat grade, so buses are able to avoid the steepest grades in the South Hills. The South Busway also enables PAT buses to bypass serious congestion at the Liberty Tunnel and to avoid the most congested roads and streets in the South Hills. Norman Voigt (1987), PAT's manager of technical services, described the South Busway as "more of a scheme to avoid congestion and difficult terrain than a comprehensive busway as we think of them today."

Buses using the South Busway save an average of 6-11 minutes over pre-busway conditions. While these time savings are obviously important, PAT officials feel improvements in reliability are even more significant: before the busway was completed, 30-40 minute delays were common (FHA, 1981). As of March 1987, scheduled inbound trip times from the first (furthest south) busway stop to downtown varied from 20 minutes to 26 minutes depending upon time of day; with few exceptions, actual trip times were very close to scheduled times (PAT, 1987c).

PAT estimates that the South Busway eliminated over 160 bus trips per day from congested streets in the South Hills. The South Busway's effect on transit ridership, moreover, exceeded PAT's expectations. PAT's 1978 Annual Report (p.2), reports that in its first full year of operations, the time savings and increased reliability provided by the South Busway resulted in ridership gains of "up to 16 percent" for the routes using the busway.

No new bus services were provided for the South Busway; existing bus routes that would gain from using the facility were simply re-routed. The 17 routes that used the South Busway in 1988 are listed in Table 6-3; they include six West Liberty Avenue routes, 10 Saw Mill Run Boulevard routes, and the single Oakland/Mt. Lebanon route. As these data indicate, six express routes (the 46BM, 46E, 46CL, 46JL, and 41CB) also use the busway.*

South Busway daily boardings averaged more than 18,000 in 1987. The most heavily patronized route, the 41B to Bower Hill, provides 61 scheduled trips per day and accounts for about 3,600 boardings per day. Buses using the South Busway charge distance related fares, which varied between $1.08 and $1.36 (1989 dollars) in March 1987. The fare structure was not altered when the South Busway opened, and no premium is charged for busway routes.

The exclusive segment of the South Busway, which is used by fewer than 400 daily bus trips in each direction, is underutilized for most of its length. The two lane (one in each direction) Mt. Washington Transit Tunnel, however, which is used by buses, streetcars and LRVs, has very little reserve capacity during peak periods. The South Busway's capacity is thus effectively lim-

* An additional three routes (47, 47D and 47S) use the shared segment of the busway from Station Square through the Mt. Washington Tunnel to South Hills Junction Station.

ited by the tunnel and particularly by the signal system which feeds buses, LRVs and streetcars through it.*

PAT's experience with the South Busway demonstrates that a short, low cost, no/low-frills exclusive busway in a heavily congested corridor with difficult terrain can produce significant service improvements and cost-savings. Experience with the South Busway convinced PAT staff and management, as well as Pittsburgh policy makers, that busways could make an effective contribution to improving transit services in the region and encouraged them to build the East Busway.

The East Busway

Starting soon after World War II, congestion steadily worsened in Pittsburgh's eastern corridor. The worst conditions existed at the entrance to the Squirrel Hill Tunnel on the Penn Lincoln Parkway, where peak period back-ups of up to several miles had become commonplace. Plans to rebuild and repair the parkway, announced by PennDOT in the early 1960's, only added to the growing concerns about traffic conditions in the corridor. PennDOT predicted it would take several years to rebuild the parkway and add a third tube to the tunnel, and that the proposed reconstruction would severely disrupt traffic. Fears of gridlock in the corridor may have been the single most important factor in the decision to include the East Busway in the EAP.

The East Busway was a compromise proposal. Available right-of-way along the Pennsylvania Railroad (precursor of Penn Central) mainline was too limited for a major road, and advocates of fixed guideway transit were unable to agree on the best rail technology, i.e. heavy rail, Skybus, or LRT. The busway was accepted as an interim solution on the condition that it would be designed so that it could be converted to LRT (Crain, 1985). Work on the South Busway continued while the EAP was being litigated, but the East Busway was delayed by litigation and by other factors.

Original plans for the East Busway assumed exclusive use of an abandoned rail right-of-way, since the Penn Central had announced its intention to discontinue service in the corridor. Unfortunately, the Penn Central railroad went bankrupt before PAT could acquire the property. When the federal government took over Penn Central and created Conrail in 1974, the new operating entity decided against abandoning the right-of-way. PAT thus instructed its consulting engineers to examine the feasibility of joint Conrail and bus operations on the Penn Central (now Conrail) right-of-way. PAT's consultants found that a busway could be squeezed into the right-of-way and still leave room for two Conrail tracks.

Accepting its consultant's recommendations, PAT acquired 73 acres of right-of-way from Conrail for approximately $19 million (1989 dollars) and agreed to rebuild the Conrail tracks so that trains could operate safely alongside the busway (Voigt, 1987). PAT also agreed to pay for upgrading Conrail's train signaling and communication systems, to allow Conrail mainte-

* We could locate no published estimates of Mt. Washington Tunnel's capacity as an exclusive bus or rail facility. Its person carrying capacity as either a bus-only or an LRT-only facility would be a function of the configuration of the tunnel right-of-way and the signaling system. Presently buses operate with 20 second spacing and LRVs with 60 second spacing.

nance vehicles to use the busway, and guaranteed that Conrail would not be required to suspend service during busway construction.

The East Busway construction project involved relocating and rebuilding Conrail track and widening the right-of-way at several points. Four Conrail tracks were replaced by two new tracks and a two-lane, two-way busway. Construction entailed building a wall to separate the railroad and busway, relocating utilities, lowering the track bed in places, reconstructing auto and pedestrian bridges, building bus ramps, and providing stairs and ramps to enable passengers to reach below-grade busway stations.

The original plan for the East Busway envisioned an 8 mile facility from downtown Pittsburgh to Swissvale. Residents of Swissvale, a middle class residential community, however, strongly resisted plans to build the East Busway through their neighborhoods. Swissvale residents were worried about noise and pollution and had concerns about security at the busway stations which would be located below grade and thus would not be fully visible from the street. As a result of this opposition, the busway's length was reduced from 8 to 6.8 miles.

PAT's current ten-year plan includes a 2.4 mile busway extension to the eastern edge of Swissvale. Swissvale citizens now support the busway. There have also been expressions of support for further extensions of the East Busway into the Turtle Creek and Monongahela Valleys east of Swissvale. Preliminary engineering for the Swissvale extension and feasibility assessment of extension beyond Swissvale are part of a current (1989) PAT Planning Analysis and Environmental Assessment.*

Characteristics of the East Busway

The East Busway is a 6.8 mile grade-separated exclusive two-lane, two-way busway between the Pittsburgh CBD and the eastern suburb of Wilkinsburg. It took less than five years to build. Construction began in August 1978 and was completed in February 1983, approximately one-year behind schedule.

The East Busway differs from most of the HOV and bus priority facilities discussed in this report in that it shares a railroad (Conrail), rather than a highway, right-of-way. The busway's width is 34 feet for most of its length; in most sections it has two 12 foot lanes, an 8 foot outbound (eastbound) right hand shoulder and a 2 foot inbound (westbound) right hand shoulder. Shoulder widths are narrower at a few points, and west of the East Liberty Station the traffic lanes are narrowed to 11 feet each for a distance of .1 mile. All stations have a stopping lane in each direction so that express buses can pass other buses that are picking up passengers at stations.

Buses using the East Busway provide three kinds of service. For most patrons, the busway combines the benefits of local bus service (residential collection and downtown distribution) with the higher performance of fixed guideway express services. Flyers and express routes pick up passengers at designated park and ride facilities and provide fast express service to the

* PAT is using Federal Section 9 funds, matched 20 percent by Allegheny County, to do the analysis of the 2.4 mile extension to Swissvale and further extension into the Monongahela and Turtle Creek Valleys.

CBD. Finally, two East Busway routes operate more or less like a rail rapid transit system and provide fast, frequent, and dependable "along the line" service to inner-city users who board and disembark at busway stations or in the downtown.

The East Busway serves 16 distinct neighborhoods, including upper middle class neighborhoods near Shadyside and Squirrel Hill and lower income neighborhoods, such as East Liberty and Homewood. As the data in Table 6-4 reveal, 31 PAT bus routes use the East Busway, 29 of these routes are express or flyer services and 2, the EBA (East Busway All Stops) and the EBO (East Busway Oakland), are "busway routes" which stop at all busway stations. Flyers are limited stop routes that serve outlying suburban communities, while express routes are limited stop routes that serve communities located closer to the eastern terminus of the busway. In contrast to the busway routes, most limited stop flyer and express routes stop at only 2 of the 6 East Busway stations, Wilkinsburg (the eastern terminus) and East Liberty. All bus routes which use the busway, except the EBO, collect and distribute passengers in the Pittsburgh CBD.*

As shown in Figure 6-5, the East Busway has 6 stations where buses can enter or leave the facility.** Station platforms are 120 feet long and accommodate 2 buses, except for the East Liberty and Penn Stations which are 240 feet long and accommodate 4 buses. Starting in downtown, the busway stations (mostly named for the major local streets they serve) are:

1. Penn Station in downtown Pittsburgh;

2. Herron Avenue;

3. Negley Avenue near Oakland and the University district;

4. East Liberty;

5. Homewood Avenue; and

6. Wilkinsburg.***

All East Busway buses operate on both the busway and on city streets, where they distribute and collect passengers. As would be expected from the East Busway's greater length and the extensive EBA and EBO operations, a higher percentage of the route miles of East Busway buses than South Busway buses are on a busway. Thirty-six percent of East Busway route miles are busway miles, the remainder are on city streets; as mentioned previously, only 26

* The EBO provides service to the employment center in Oakland and the University District, east of the Pittsburgh CBD.

** Two additional stations, at the Fifth Avenue and Braddock Avenue bridge crossings were considered, but not built; patronage projected for these stations was too low to justify their cost (Voigt, 1989a).

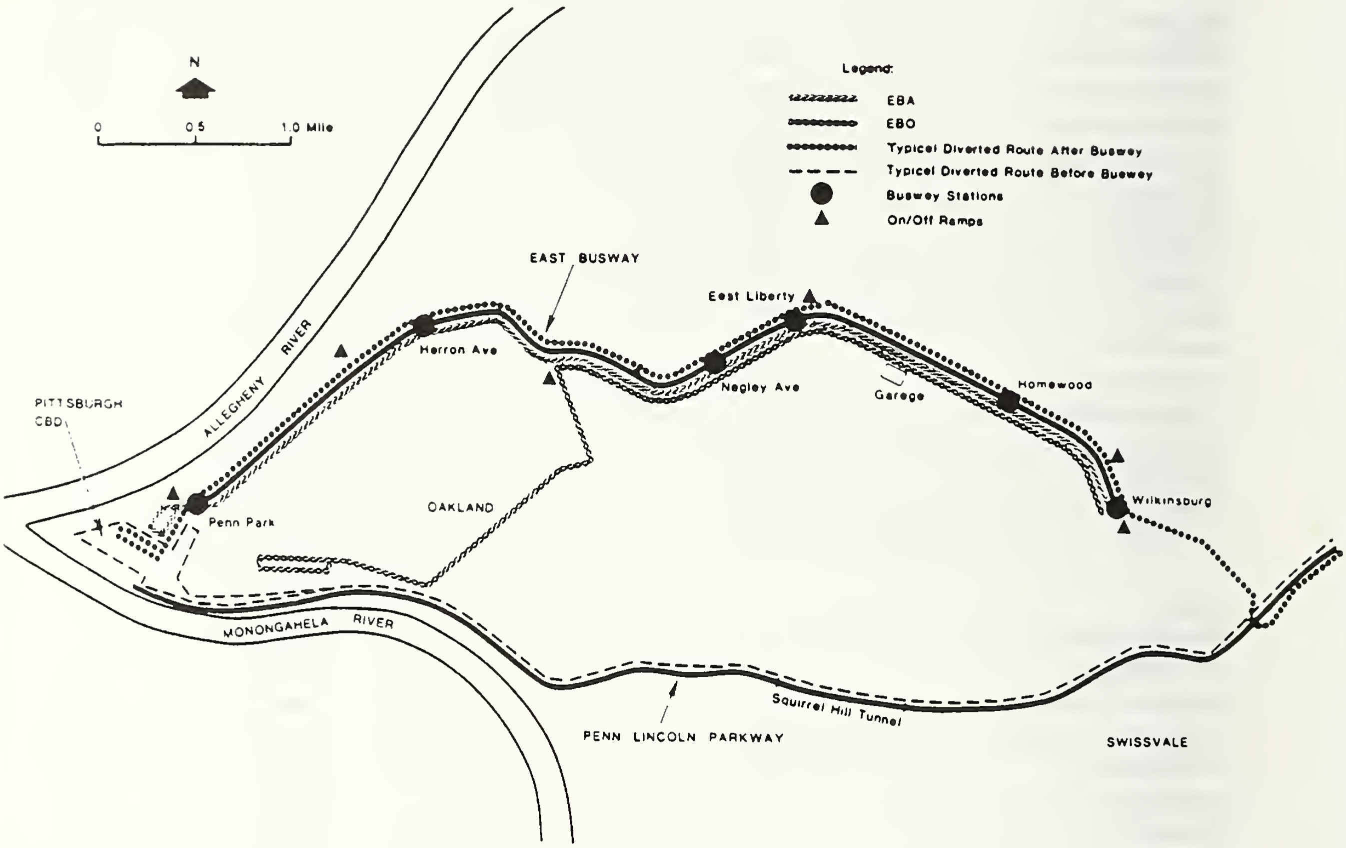
*** Buses enter the busway at Penn Station after collecting passengers on city streets. Users are able to transfer to the East Busway at Penn Station from other PAT bus routes, the LRT system, Amtrak and Greyhound. Five routes, including the EBO, exit/enter the busway on a ramp at Neville St., located approximately halfway between the Herron Ave. and Negley Ave. stations. East Liberty is the busiest station/stop in the PAT system and site of the East Liberty Bus Garage; Seven routes exit/enter the busway there. 20 busway routes enter/exit at Wilkinsberg, the busway's eastern terminus from the city streets.

Table 6–4. East Busway Bus Route Summary Statistics

Name	Route No.	Scheduled Trips	Riders Per Day	Ridership/ Scheduled Trip
Express Routes				
Blawnox/Oakland	4U	13	486	37
North Braddock	63A	25	1,418	57
Rankin Express	63B	22	1,175	53
Oak./Monroeville	67U	1	41	41
Monroeville	68A	10	465	47
Blackridge	68B	8	427	53
Wilkensburg	68D	32	1,770	55
Trafford	68F	10	606	61
Swissvale	68G	24	1,048	44
Lincoln Hwy	68J	10	819	82
Highland Park	73B		512	
Frankstown East–Vue	77E	9	257	29
Oak./Frankstown	77U	5	150	30
Oakmont	78A	18	1,092	61
Shadyside	78C	4	83	21
East Hills	88A	10	397	40
Flyers				
Allegheny Valley	AV	7	498	71
Ally. Valley North	AVN	6	333	56
Greensburg Pike	G	2	86	43
Greens. Pike/Rainbow	GR	4	180	45
Holiday Park	HP	13	806	62
Lincoln Park	LP	22	1,260	57
Monroeville	M	6	235	39
Penn Hills	P	6	98	16
Penn Hills Gateway	PG	22	1,073	49
Trafford	T	3	96	32
East Vue	U	2	80	40
Wilkens Ave.	W	8	208	26
Total Express East Busway		302	15,699	
East Busway Routes				
EBA		154	11,812	77
EBO		37	1,605	43
Total East Busway Routes		191	13,417	70
Total East Busway		493	29,116	

Source: PAT Ridership Analysis, March, 1989

Figure 6-5. East Busway: Routes and Stations



percent of South Busway route miles are on the busway itself (Voigt, 1989a). East and South Busway bus routes cross in the Pittsburgh CBD, so riders are able to transfer between the two busway services.

Fares in 1988 charged for East Busway services vary from $1.04 for the EBA and EBO to $2.61 (in 1989 dollars, $1.00 and $2.50 respectively in nominal dollars) for some flyer and express routes. Like the South Busway, no premium fares are charged for East Busway services. As with all PAT routes, fares are collected when passengers board on inbound trips and when they leave on outbound trips. Collecting both inbound and outbound fares at the residential end of the trip markedly increases the effective capacity of stops and bus lanes in the critical downtown area (see Chapter 12).

East Busway Operations

When PAT opened the East Busway, it initiated 5 new routes (EBA, EBO, 73B, 78C and 88A). An additional 21 suburban flyer and express routes (mostly routes that operate only dur-

ing peak periods) were re-routed from the Penn Lincoln Parkway to the busway for the final segment of their trips to the downtown. Two years after the busway opened, two express routes (63A and 63B) were added in the eastern corridor.

As mentioned previously, the major new East Busway route, the EBA, operates much like a rapid rail system. The route runs from the eastern end of the busway to downtown Pittsburgh, stopping at all 6 busway stations before it makes a distribution and collection loop on the CBD streets. Only articulated buses are used on Route EBA. When the East Busway first opened, the EBA had 6 minute headways, but PAT soon increased frequencies to 4 minutes and then to 2-to-3 minutes in response to a steady growth in demand. EBA patrons mostly walk to busway stations or transfer to the EBA from connecting local non-busway service.

The EBO operates in the same fashion as the EBA, except that it does not serve the Pittsburgh CBD. Instead, as Figure 6-5 indicates, it exits the busway short of downtown and provides direct service to the Oakland area east of the Pittsburgh CBD. The University of Pittsburgh, Carnegie Mellon University, and several major hospitals are all located in Oakland, making it a major employment destination.

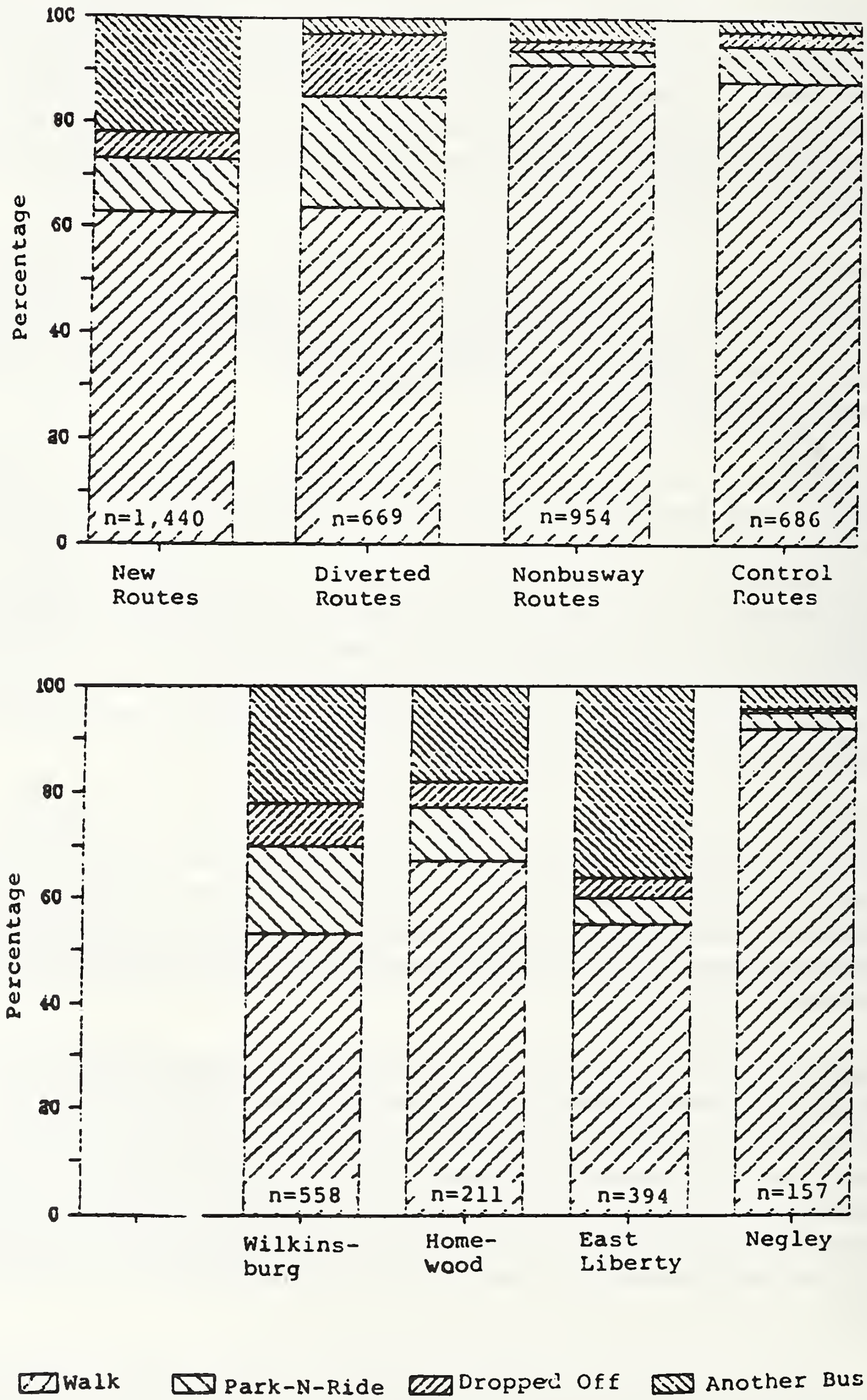
East Busway stations serve as mini-hubs and transfer points for local, eastern corridor, non-busway services. Passengers from connecting local services are able to transfer to the EBO or the EBA at these stations and continue to downtown Pittsburgh, to Oakland, or to stations and transfer points along the busway. Physically, the East Busway stations are midway between the "simple" South Busway stops and "full service" stations provided for the South Hills LRT (see discussion below). East Busway stations, which resemble the simple below grade stations found in many commuter rail systems, provide cover and benches for waiting passengers and bridges for crossing to the opposite side. They are open, visible from adjoining streets, and are well lit so that security can be maintained by observation from passing police cars.

As Figure 6-6 indicates, users of all East Busway routes (new and diverted), and particularly the EBA and EBO (new routes), are much more likely to transfer than users of PAT eastern corridor bus routes that do not use the busway (non-busway routes) or routes serving other parts of the region (control routes). These results, of course, reflect the design of the busway route system, and in particular the nature of the EBA and EBO services, which are functionally equivalent to rail operations.

Express and flyer buses have significantly different ridership patterns than do the EBA and EBO. Only one percent of the users of express and flyer buses on the East Busway transfer to or from another bus, while 33 percent either park and ride or are dropped off ("kiss and ride"). Suburban park and ride users typically park at free lots provided by PAT at various suburban locations located beyond the end of the East Busway. As was true of the South Busway, and unlike the South Hills LRT, none of the East Busway stations have park and ride facilities. Some riders who board along the busway, however, park on local city streets and private lots and walk to stations.

As Table 6-4 indicates, over 29,000 person trips a day were made on the East Busway in March 1989. As of 1989, the two "busway routes" carried 46 percent of all East Busway riders. The EBA with nearly 12,000 boardings per day is by far the most heavily patronized East Busway route (PAT, 1989). The EBO averaged approximately 1,600 daily boardings. The East Busway

Figure 6-6. East Busway: Mode to Bus Stop by Route and Station



express and flyer routes carried the remaining 54 percent of busway passengers. The preponderance of these trips are to or from downtown Pittsburgh; 87 percent of inbound suburban express busway riders, are destined for the Pittsburgh CBD (Crain & Associates, 1987).

There are approximately 260 peak period (6:45 to 9 AM and 3:30 to 5:45 PM) bus trips (both directions) on the East Busway; 90 of these are in the peak hour peak direction (Biehler, 1989). The East Busway operating speeds are 50 mph over most of its length. All buses are required, however, to slow to 25 mph at stations and for the 0.1 mile segment where the traffic lanes narrow to 11 feet and ramp speed limits are 15 mph. Express routes average about 45 mph on the busway during the peak while the EBA route, with its greater number of stops, averages 31 mph (Crain, 1987; Biehler, 1989).

Riders on both new local and diverted (suburban express) routes obtained large travel time savings from the East Busway. Crain and Associates (1987, p. xiv.) estimate that the travel times of EBA passengers declined by 21 to 24 minutes, a reduction of 40 to 45 percent. Even EBA passengers who previously did not have to transfer experienced travel time savings of between 8 and 12 minutes (Crain, 1987).

Express and flyer bus passengers saved approximately 8 minutes on average during the AM peak, relative to pre-busway conditions. These savings, which allow for increases in trip length due to re-routing, reflected decreases in in-vehicle time achieved primarily from bypassing the heavy congestion on the Penn Lincoln Parkway. Since PM peak period congestion on the Penn Lincoln Parkway is much less severe than AM peak congestion (Crain, 1987), time savings during the PM peak are much smaller (an average of 3.5 minutes) and are primarily due to reductions in downtown in-vehicle and walk times.

The consistency of travel times on busway routes is another factor contributing to the East Busway's impressive ridership. Local street congestion causes street running times to vary significantly; buses on the busway operate in a congestion free environment and are able to maintain published schedule times.

Most East Busway passengers used the same routes or other PAT bus services before the busway was opened. Even so, Crain and Associates (1987, p. xv) found that 11 percent of those using suburban express (diverted) routes previously made their trips by car. The same study found that corridor transit ridership increased by 1-2 percent after the East Busway was completed. These estimated increases may seem small, but they occurred at a time when a major fare increase caused sharp ridership declines throughout the PAT system (Crain, 1987).

Future Busway Plans

As mentioned previously, PAT is currently studying an East Busway extension to Swissvale and possible further extensions into the Turtle Creek and Monongahela Valleys. Extension of the East Busway into the depressed steel communities scattered along Turtle Creek and the Monongahela River is viewed by the Monongahela Valley Commission (1987, p.58) as a critical component of economic revitalization plans for the area. The proposed extension would provide a direct link between the steel communities, the CBD and the growing business activity near the University of Pittsburgh and Carnegie-Mellon University (Gittell, 1989).

PAT, which owns and operates the East and South Busways, has been reluctant to allow carpools or vanpools to use their busways, even though there appears to be considered excess capacity during peak hours, at least on the East Busway.* Prior to 1983, the Southwest Pennsylvania Regional Planning Commission (SPRPC) attempted, on several occasions, to persuade PAT to allow vanpools to use the East Busway, but PAT resisted. PAT refused on the grounds of safety and because they felt the anticipated use of the busways by 90 to 100 buses per hour would leave room for relatively few car or vanpools. According to Biehler (1989), SPRPC now agrees with PAT on the safety issue, and has not urged PAT to allow carpools and vanpools to use the busways for some time. The only non-transit vehicles that PAT presently allows on the busways are emergency vehicles on both busways and Conrail maintenance vehicles on the East Busway.

Because the facilities have on-busway stations, PAT contends carpool use of its busways poses much greater safety risks than would occur with bus-HOV facilities, such as the Shirley Highway and the Houston transitways, which do not have on-line stations. PAT officials fear that motorists would tend to treat the busways as interstate highways and drive at high speed. While the East and South Busway stations have pedestrian crosswalks, this would make the crosswalks and station areas, as well as curves where 25 mph speed limits are posted, potentially dangerous locations. Support for PAT's concerns about safety are provided by the fact that the only two major collisions that have occurred on the East Busway have involved non-PAT vehicles, a county police car and a bicycle illegally using the busway (Biehler, 1989).

While PAT officials deny it, PAT may also be worried that allowing carpools and vanpools to use the busways would reduce transit ridership and revenues. One can only wonder what PAT's posture toward carpools would be if it was given permission to operate the East Busway as a toll road.

Setting aside safety concerns and issues of legal and political feasibility, a strong case can be made for allowing PAT to charge carpools for the use of the East Busway. Since busway use by carpools would be voluntary, those using the facility and paying the toll would, by definition, be receiving benefits that are equal to or larger than the tolls they posed. Any surplus toll revenues could be used to subsidize transit services. Tolls could be set at levels that would insure that the number of carpools using the busway would remain below levels that degrade transit performance through an appropriate pricing scheme. Transit time savings from busway usage and transit ridership, which depend on transit time and reliability, could thus potentially be maintained, even with carpool use of the busway.

Other Busway Plans: A West Busway

SPRPC, the region's transportation planning body, has been actively considering transport improvements that would serve the western part of Allegheny County, particularly the growth area west of the CBD and near the airport. A local real estate entrepreneur, Jack

* Michael Baker Jr., Inc. (1985) conservatively sets minimum East Busway headways at 24 seconds for a capacity of 180 buses per hour in each direction; currently 90 buses use the East Busway during the peak hour in the peak direction. These capacity estimates suggest that PAT uses only 50 percent of the East Busway's capacity currently. As we observed previously, there also appears to be excess capacity on the bus-only segment of the South Busway, but its overall capacity is limited by the Mt Washington Transit Tunnel, signaling and stations which it shares with LRVs and streetcars.

Buncher, has offered to sell PAT an abandoned railway right-of-way for an "Airport Busway." The proposed 4.2 mile facility, which would run from Station Square in downtown to the West End, then to Carnegie, and finally on to the airport, would enable buses to avoid heavy congestion on the West Parkway. Buncher has made vigorous efforts to generate public support for the scheme and has threatened to sell the right-of-way to private developers unless action is taken quickly. Many public entities in Allegheny County are in favor of an "Airport Busway." PAT has initiated analysis to fast track the proposed Airport Busway and is considering financing methods, including alternatives that would not require federal funding (Biehler, 1989).

Despite the well documented success and the clear-cut operational advantages of the South and East Busways, there continues to be opposition to building new busways. Even more surprising, there are continuing proposals to convert the East and South Busways to light rail. To gain further perspective on these questions, we now consider Pittsburgh's recent experience with LRT.

The South Hills LRT

The South Hills corridor has long been an important transit corridor. During 1965, transit boardings, including both bus and streetcar services, averaged 75,000 per day. Approximately 25,000 passengers per day made their journeys on PAT's deteriorating 24-mile streetcar system. In 1969, as part of the Early Action Program (EAP), PAT proposed replacing this aging South Hills streetcar system with the TERL (Skybus). The TERL proposal encountered stiff local resistance and was opposed by the Governor.

In response to a February 1975 UMTA deadline for EAP funding and in light of the Governor's support of light rail, the PAT board appointed an eight-member Transit Task Force (TTF); the task force, in turn, hired DeLeuw, Cather & Company to complete an independent evaluation of the South Hills Corridor. At the urging of PAT and the TTF, the consultants examined the following alternatives: Skybus, LRT, Rail Rapid Transit (Metro Rail), and Express Bus Transit (EBT) System. DeLeuw, Cather found there were no significant travel time differences among the four alternatives and determined that all four would carry about the same number of trips in the year 2000. As Table 6-5 shows, projected year 2000 ridership varied from a high of 170,500 trips per day for the EBT to a low of 166,400 for rail rapid transit. The issue quickly became choosing between the LRT system, proposed by the Governor and various local officials, and the EBT system.

The alternatives analysis indicated that the LRT and EBT would provide similar levels of service, that both would have average operating speeds in the 16-22 mph range, and that both would provide two minute peak-hour headways. DeLeuw, Cather recommended LRT because of "its lower net project costs" (yearly operating plus annualized capital cost), concluding that LRT operating revenue and subsidy requirements for the period 1982-2000 would be only 51 percent as large as for the competing express bus system ($938 million as compared to $1.86 billion in 1989 dollars).* DeLeuw, Cather found, moreover, that the express bus alternative would

* The economic evaluation assumed UMTA would pay 80 percent of the capital costs and 50 percent of the operating subsidies of all four alternatives, and thus emphasized local costs.

Table 6–5. System Characteristics, Ridership, and Cost of South Hills Alternatives (costs in 1989 dollars)

Item	TERL (Skybus)	LRT	Metro Rail	EBT (Busway)	Ratio EBT/LRT
Route Miles	10.4	22.3	10.4	14.8	0.66
Stations	12	54	12	46	0.85
Daily Ridership (Yr.2000)	168,700	170,400	166,400	170,500	1.00
Costs (millions of dollars)					
Capital	$968.8	$802.1	$856.3	$639.6	0.80
Annual Operating	$54.8	$48.6	$46.2	$73.1	1.50
Capital Costs/Mile	$93.1	$36.0	$82.3	$43.2	1.20
Operating Costs/ADR (in dollars)	$1.51	$1.42	$1.33	$2.13	$1.50
Net Project Cost		$937.6		$1,855.9	

Note: 'Net Project Cost' is yearly operating costs plus annualized capital costs calculated by Deleuw, Cather & Company.
Source: Deleuw, Cather & Company, 1975.

have the highest net projected cost of the four alternatives, even though its capital costs were substantially less than any of other three alternatives. As the data in Table 6-5 indicate, the estimated capital costs of the EBT were only 80 percent as large as for the proposed LRT. Net project costs for the bus system were higher because projected operating costs were 50 percent higher than the LRT alternative which more than offset the EBT's lower capital costs. As Table 6-5 indicates, the EBT alternative had the highest projected operating costs of any of the four alternatives.

As we discuss further below, actual LRT operating costs are much higher than projected levels, principally because overly "optimistic" assumptions were used in forecasting operating costs. For example, while Deleuw, Cather (1975) assumed all LRT stations would be unmanned, some are manned. Of the 13 surface stations, 6 are manned on a part-time basis, during peak periods to allow off-board fare collection that speeds vehicle boarding and operation; the three subway stations downtown are patrolled by PAT police on a full-time basis. For these and other reasons, LRT operating costs are higher than those assumed for the South Hills alternative analysis.*

Ultimately PAT justified its selection of LRT primarily in terms of the benefits of having a downtown subway. The fact that EBT would use considerably more surface street space during peak periods than LRT was considered a major drawback. While this argument is correct, no serious effort was made to quantify the costs of CBD bus operations. Nor, as far as we know, was the possibility of a bus tunnel that might have also been used by East and South Busway vehicles ever considered.

* PAT officials now agree that their LRT system is more expensive to operate than their busways. However, they contend this is due to factors other than part-time station attendants. At the time the DeLeuw, Cather study was done (1976-76), there were no exclusive busways in operation and PAT contends that the operating cost estimates appeared reasonable at the time they were proposed even though they overestimated the advantages of LRT over busways (Biehler, 1989).

With the release of the DeLeuw, Cather study "documenting the advantages" of LRT, with federal funding for LRT capital costs, and with the Governor's active support, the selection of LRT could hardly have been a surprise. In April 1976, the Port Authority Board unanimously accepted the recommendation to build an LRT in the South Hills and instructed PAT management to seek additional federal assistance for final engineering and environmental studies. In October 1976, UMTA agreed to fund the first 10.5 miles of the proposed 22.3 mile LRT system.

Description of Stage I LRT

Over ten miles of Pittsburgh's existing 22.5 mile South Hills trolley system were rebuilt to modern LRT standards in Stage I. Completion of Stage I entailed new construction, adaptive rehabilitation of abandoned railroad facilities, and reconstruction of one of the two interwoven trolley lines in the South Hills. The other line of the original streetcar system continues to operate with Presidents Conference Committee cars (PCCs).

The Stage I LRT, shown in Figure 6-7, is primarily at-grade. The 10.5 miles of the Stage 1 route includes:

1. A 0.7 mile downtown subway;

2. A PAT bridge crossing over the Monongahela River to Station Square;

3. The Mt. Washington Transit Tunnel, which the LRT shares with South Busway buses and PCC cars from the South Hills trolley line;

4. South Hills Junction Station just south of the Mt. Washington Tunnel, where the LRT line splits from the South Busway and the trolley line; and

5. Rebuilt LRT track and stations from South Hills Junction to South Hills Village, including a new 3,000 foot tunnel through Mt. Lebanon at a particularly congested and hilly part of the route.

In comparison to the other LRT systems built in North America during the past 10-15 years, the Pittsburgh system has an unusually large number of stops, 35 within a stretch of only 10.5 miles, for an average stop spacing of only 0.3 miles.* In addition, there are many grade crossings and significant stretches of the line, as in the case of the old trolley system, operate on surface streets in mixed traffic. As a result, average speeds are low and travel times are quite long. The Pittsburgh system is also unusual in its use of both high and low platforms, a feature that was included so that the system could accommodate both new LRT vehicles and old PCC cars, and safety island stops for on street operations.** Five of the Stage I LRT Stations in the

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* Station spacings for other new systems are Buffalo (0.9 miles), San Diego (1.9 miles), Portland (1.1 miles), Sacramento (1.4 miles) and San Jose (1.1 miles) (CRA, 1988, p. 11-15).

** Thirteen of the stations including all four subway stations, Station Square, South Hills Junction, and the seven new and upgraded surface stations along the old Mt Lebanon line that were included in stage I have both high and low level platforms. An additional 23 stops have only low-level platforms, these are stops without stations. LRVs can stop at low level and high level stations and stops while PCCs/street cars require low platforms.

Figure 6-7.

Pittsburgh's Light Rail Transit System

South Hills have park and ride lots, with a total of 2,100 parking spaces.

The most costly parts of the Stage I LRT project are the 0.7 mile downtown subway and the 3,000 foot tunnel through Mt. Lebanon. Three of the remaining components, from north to south, the PAT (previously Conrail) Bridge over the Monongahela River, the Mt. Washington Transit Tunnel, and the 9 miles of track on the old Mt Lebanon street car line were part of the South Hills streetcar lines, but required significant upgrading to meet LRV specifications.* This upgrading included rebuilding facilities to modern double track standards and converting power supply and signaling stations to LRV specifications.

As noted above, the fact that a new downtown subway would remove the South Hills streetcars from the downtown surface streets and thereby would reduce CBD congestion was a major "selling point" for the Stage I LRT project. Advocates of the new system argued further that it would provide additional congestion relief by encouraging many auto commuters to the CBD to switch to transit.

As Figure 6-7 indicates, the new LRT-streetcar downtown subway is Y-shaped; the east-west segment includes stations at Steel Plaza, Wood Street and Gateway Center, while the north-south leg uses an existing Conrail tunnel to link Penn Station and the new Steel Plaza station with South Station and the rebuilt LRT-trolley system south of the Monongahela River. The Conrail tunnel, which was built of cut stone and brick by the Pennsylvania railroad in 1865, was repaired and reinforced with a concrete lining. Construction of the new downtown LRT subway thus combined new construction and reconstruction of the existing railroad (Conrail) tunnels.

Even though PAT was able to use the former Conrail tunnel for a significant part of the subway's length, the tunnel was still expensive. Completing the tunnel entailed difficult and costly construction problems; as a result, it cost $91 million (1989 dollars) to build, an amount that accounted for over 15 percent of total Stage I project costs (Voigt, 1987). Because of wet and sandy soil in the aquifer underlying the downtown area, the new section of Pittsburgh's subway had to be built by cut and cover. Its construction was greatly complicated by the fact that the streets in downtown Pittsburgh are unusually narrow. As a result, the new tunnel often extended all the way to the foundations of existing buildings, requiring difficult and costly measures to support the foundations of these structures during and after construction.

The need for a new 3,000 foot tunnel through Mt. Lebanon also added substantially to total system costs. The new tunnel enabled LRVs to by-pass Washington Road, a heavily congested north-south artery that passes through the Mt. Lebanon business district. According to Beim (1988, p. 45), the Mt. Lebanon tunnel saves transit users 20 minutes of peak hour travel time in comparison to the previous streetcar route. The Mt. Lebanon tunnel cost $19.1 million (1989 dollars) to build and was bored using a new Austrian method for rock tunneling.

* As the LRT system is presently configured, LRVs leave the downtown subway and use the PAT bridge (acquired by PAT from Conrail after it abandoned its Panhandle Extension in 1980) to cross the Monongahela River. PAT rehabilitated the former Conrail Panhandle Bridge with new approach structures at the south end of the bridge to connect it to the Mt. Washington Transit Tunnel.

Total capital costs for Stage I also included a sophisticated LRV maintenance facility. PAT built a new rail center that provides a storage yard and maintenance shop for the entire PAT rail car fleet, and a LRT operations control center on a 50-acre site adjacent to a new light rail terminal at South Hills Village.

PAT's Stage I LRT system was built in three segments, beginning at both ends and working towards the middle. Work on the south end, where the new rail maintenance facility is located, began at the end of 1980. Reconstruction of track south of Castle Shannon (Figure 6-7) began in September of 1982, and this segment of the system was returned to rail service in 1984. Utility relocation and preliminary work on the downtown subway also began in 1980. Even so, construction of the subway did not begin in earnest until January 1982, when PAT gave its contractors until November 1984 to complete the bulk of the work, a schedule designed to minimize the disruption to downtown traffic during the Christmas shopping season. The subway finally opened in July 1985.

PAT originally expected that the LRT would be fully operational in 1983, but the project experienced more than its share of setbacks. The most serious was an UMTA decision to spread the federal 80 percent share of project costs over eight, rather than five years. Construction problems caused other delays. For example, just before the entire system was to be opened in late 1986, PAT inspectors found defects in five miles of overhead catenary wire; correction of this problem delayed the system's formal opening until May, 1987.

PAT maintained transit service throughout the construction period with a combination of trolley and substitute bus services. As Figure 6-8 indicates, however, service interruptions and delays took their toll on rail (streetcar/LRT) ridership. Rail ridership fell sharply between 1981 and 1984 and boardings in 1984 were only 53 percent of those in 1981. These data, however, overstate the loss in system ridership as many South Hills streetcar riders used temporary replacement bus services during the construction period. With the system's completion in 1987, rail ridership increased sharply. Nonetheless, LRT ridership has remained well below forecast levels: rail boardings in 1988, including downtown subway ridership, were only 15 percent higher than in 1980 (33,000 per day compared to 28,600). This after the expenditure of $523 million (1989 dollars). In contrast, PAT bus ridership declined only 10 percent over the same period even with diversion of some riders, particularly in the CBD, to LRT.[*] It is probably true that bus routes using the South and East Busway did much better than the system's average. However, we lack the data required to make a precise comparison.

LRT Operations

PAT operates its 10.5 mile Stage I LRT line with 55 new 82-foot, 170 passenger LRVs. The double-ended and articulated LRT vehicles were purchased from Siemens-Duewag for approximately $1.1 million each in 1989 dollars. Since the LRVs are too wide and heavy for use on the old trolley line, they can only be used on the rebuilt sections; PAT's remaining 45 PCC cars can operate on either old or new sections of track.

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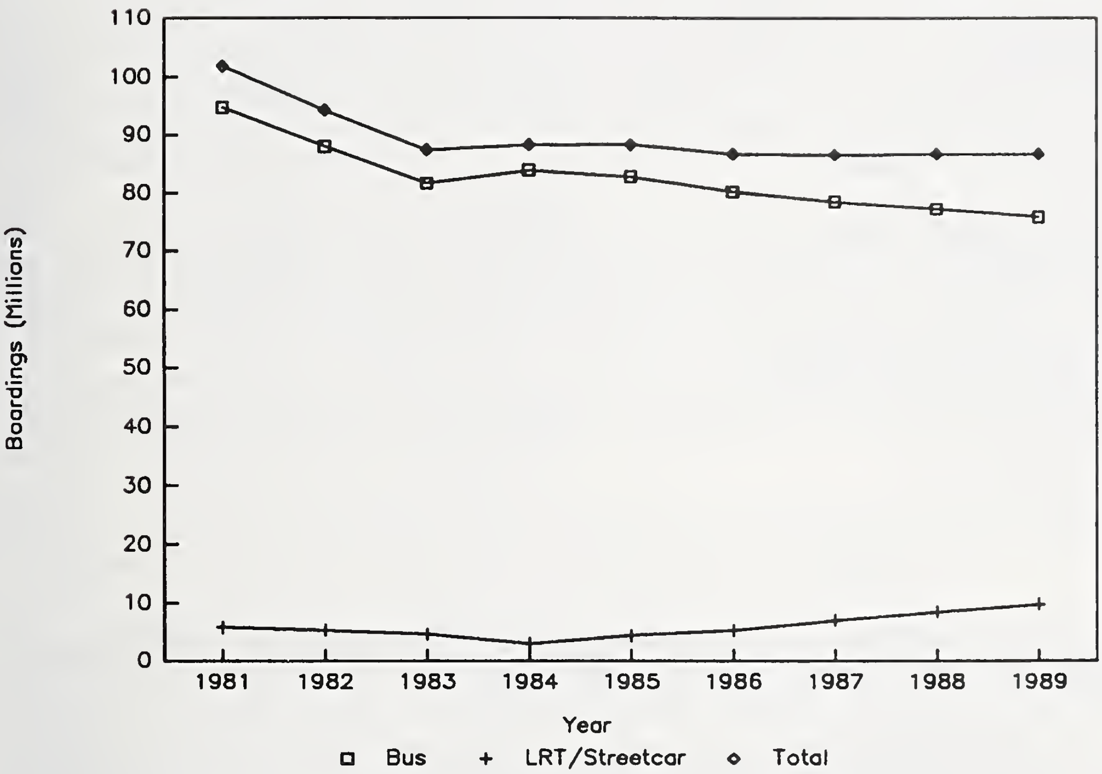
[*] Both the Draft and Final EIS claimed there would be more than 90,000 daily LRT and streetcar riders in 1985, two years after full operations were to have begun.

Figure 6-8. Annual Boardings by PAT's Bus and Rail Services by Year, 1981-1989



Comparative Cost and Performance: LRT vs. Busways

Biehler (1988) has recently completed an analysis of the comparative cost and performance of Pittsburgh's busways and its Stage I LRT system. As the data in Table 6-6 indicate, Pittsburgh's 10.5 mile LRT cost approximately $523 million (1989 dollars) or approximately $50 million per mile.* These data indicate further that the LRT capital cost per mile was five times the per mile cost of the South Busway and 2.5 times as much as the per mile capital costs of the East Busway (after adjusting all facility construction costs to 1989 dollars).

Reflecting low property acquisition costs, "minimalist" design, and lack of amenities, the South Busway cost significantly less to build than the East Busway. The South Busway had low right-of-way costs because it was built on relatively inexpensive railroad "slope" property. As the data in Table 6-6 indicate, the South Busway cost $38 million to build in 1989 dollars, approximately $9.4 million per mile. According to Voigt (1987), construction costs accounted for 83

* DeLeuw, Cather (1976) estimated the entire 22.3 mile LRT system could be built for $800 million in 1989 dollars ($384 million in 1975 dollars) or $36 million per mile. Pickrell (1989) provides an estimate of $634 million in 1989 dollars for the same system and finds, moreover, that the actual cost of Pittsburgh's 10.5 mile LRT system was only 89 percent of the projected cost. Pickrell uses the Final EIS figures in order to be consistent with data used for other cities and because the Draft EIS corresponds more closely to the decision to build the project.

Table 6–6. Performance and Cost Comparisons: Stage I LRT Compared with Busways (costs in 1989 dollars)

Item	South Hills LRT (Stage I)	East Busway	South Busway
Years To Complete	7	5	2
Length (miles)	10.5	6.8	4.0
Average Daily Ridership	18,000	29,000	18,000
Costs (millions of 1989 dollars)			
Capital	$523.0	$138.1	$37.7
Annual Operating (Yr.2000)	$8.8	$4.0	$3.3
Capital Costs/Mile	$49.8	$20.3	$9.4
Operating Costs/ADR (in 1989 dollars)	$1.32	$0.47	$0.61
Adjustments (millions of 1989 dollars)			
Total Capital Cost			
W/O Subway	$429.9		
Capital Costs Per Mile			
W/O Subway	$45.7		

Source: Biehler, 1988.

percent of total South Busway costs, while property costs were $1.34 million (1989 dollars); the remaining costs were for design and miscellaneous items.

Biehler similarly estimates the East Busway cost $138 million (1989 dollars) to build, or $20 million per mile. East Busway costs per mile exceed those for the South Busway because stations were provided along the busway; the East Busway had higher property acquisition costs ($18.9 million in 1989 dollars); and costs were incurred in relocating the Conrail tracks and building a wall to separate the tracks from the busway.

Stage I of the South Hills LRT included the downtown subway, which significantly added to project costs. Subtracting subway construction costs from Stage I LRT costs provides a somewhat fairer comparison of busway and LRT costs.* This comparison is still slightly biased against the South Hills LRT because there were no segments of the East or South Busway that required construction of tunnel as did Stage I LRT in Mt. Lebanon. As Table 6-6 indicates, subtracting both the costs and the mileage of the downtown subway reduces the Stage I LRT costs to $430 million (1989 dollars) and the per mile cost to $45.7 million. The per mile capital costs of the Stage I LRT thus substantially exceed those of the East and South Busways, even when allowance is made for the higher than average capital cost of the downtown subway.**

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* Busway buses operate on city streets in the downtown. As mentioned previously, no consideration was given to the possibility of building a bus tunnel in the CBD.

** In determining the proper investment for the South Hills, another comparison could be EBT, as used in the DeLeuw and Cather report, with the costs of a downtown bus tunnel added. Given the high costs of bus tunnel construction (see discussion of the Seattle bus tunnel in chapter 13 and of the proposed Ottawa bus tunnel in Chapter 5), the comparative costs of the downtown portion of an EBT and the LRT might be similar. This suggests that the discussion in the text of comparative system costs without the downtown subway is most relevant. It is interesting to note that Seattle's bus tunnel was designed to accept LRVs as well as buses which increased tunnel costs somewhat. In contrast, the design of the downtown subway in Pittsburgh

Operating Costs

Biehler (1988) also developed estimates of the annual operating costs of the Stage I LRT system and the East and South Busways. He reports the South Hills LRT system cost $8.8 million per year to operate in 1989 dollars. As Table 6-6 reveals, the annual operating cost of the South Hills LRT exceeds the combined operating costs of the South and East Busways.* In developing his busway operating costs, Biehler includes only the costs of bus operations on the busway; he excludes feeder bus costs, even when the buses operate as their own feeders, to make them comparable to the LRT. He does include operating costs for the downtown portion of the busway routes, however.

By late 1987, total ridership on the Stage I LRT, including the downtown subway, had grown to an average of 33,000 per day.** The East Busway with 29,000 riders per day carried nearly as many riders. Ridership on the South Busway averaged 18,000. Therefore, on a operating cost per passenger basis the Pittsburgh busways have thus far significantly outperformed the stage I LRT. Biehler (1988) estimates that the operating cost per passenger for the LRT was $1.32 in 1987, as compared to $0.47 and $0.61 per passenger for the East and South Busways respectively (all figures are in 1989 dollars).***

Pittsburgh's Experience with LRT and Busway: An Overall Assessment

The Pittsburgh experience with operating LRT and exclusive busways in the same city, provides a useful comparison. Thus far, Pittsburgh's exclusive busways have significantly outperformed the South Hills LRT. The busways carry nearly as many passengers on much shorter and less costly facilities. This may explain the comments by Theodore Hardy (PAT's director of Engineering and Construction) at an October 1987 HOV conference, where he observed that "a busway might well have been the better choice for the South Hills rather than LRT, considering the cost and complexity of operation."

As Biehler (1988) has pointed out, the principal advantages of busways are that they can be shorter in length, are less costly to construct per mile, have lower operating costs at low-intermediate volumes, and yet can carry as many riders as LRT systems. Bus transit systems, moreover, are more flexible and can adapt to changes in the spatial distribution of population and employment and transit demand. Buses can provide most transit passengers with direct (no transfer) rides, while LRT systems have to depend on feeder buses to collect a significant percentage of their passengers.

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does not provide room for buses, the tunnel cross-section was kept tight against LRVs, virtually eliminating the possibility of running buses through the tunnel.

* Operating costs include the full cost of transportation, vehicle and facility maintenance, fuel and utilities, and administrative overhead in the transportation and maintenance areas.

** Ridership in the downtown subway averaged 15,000 while ridership on the at grade section of the LRT in the South Hills was 18,000.

*** This comparison may not be completely fair to the LRT, because as Biehler points out, the busways are shorter than the LRT and the average LRT trip may be longer than the average busway trip.

Busways are normally shorter than LRT lines in similar corridors because in areas with little congestion buses can operate on arterial streets with little or no performance penalty. Of course, LRT systems could save nearly as much by using longer feeder routes, but for some reason rail system planners and operators invariably feel compelled to extend existing rail lines, even when the extensions are clearly uneconomic. Because busways do not require extensive overhead wiring systems, signals, and trackage, the capital costs per mile of busways are significantly lower than those of LRT systems.

Alternative analyses comparing busways to LRT, including the previously mentioned analysis conducted for the South Hills corridor, invariably assume LRT systems have significantly lower operating costs. Pittsburgh's experience is contrary to this widely held view.

Future Transit Plans

Pittsburgh's experience with busways has clearly been a positive one and, as reflected in planning for an Airport Busway, there is growing support for building more busways. It would be a mistake, however, to conclude that either Pittsburgh or PAT have abandoned rail. Long-term transit plans for the region include proposals to complete the Stage II of the South Hills LRT project, and a proposal for a completely new rail transit line in the eastern corridor.

A Stage II South Hills corridor study is considering numerous alternatives including rebuilding the remaining 12 miles of South Hills streetcar lines to modern LRT standards, rebuilding the 12 miles to lower cost LRT design standards, and replacing the trolley lines with a busway. A final decision is expected after completion of the study in 1990. The most recent estimate suggests that rebuilding the remaining South Hills streetcar lines to modern LRT standards would cost an additional $300 million (assumed to be 1989 dollars); this would bring the total cost of the 22.3 mile South Hills LRT system to over $820 million (1989 dollars).*

Spine Line Corridor Project

The so-called "Spine Line" corridor, shown in Figure 6-9, extends from the Pittsburgh CBD eastward to Oakland, the North Side, and Squirrel Hill. The CBD has the highest employment density in Allegheny County; Oakland is the region's educational and medical center; the North Side includes a strong mix of employment, retail and residential activities; and Squirrel Hill is a regional shopping center and major residential area. Not surprisingly, this corridor also has the highest levels of current transit use and, as mentioned previously, has been the subject of rapid transit studies since the early 1900's. Bus routes currently serving the Spine Line corridor, including East Busway routes, carry over 90,000 riders per day (Baker, 1985).

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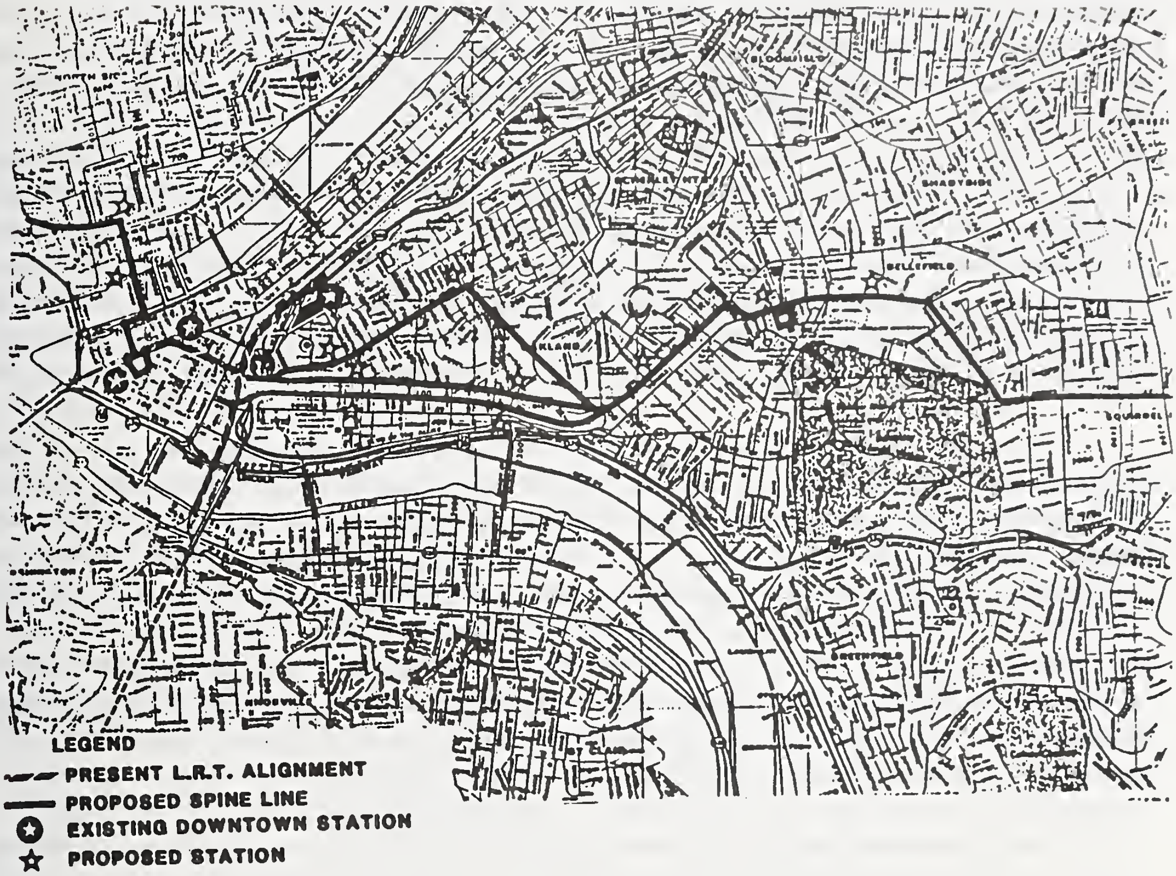
* In late 1988, the 5.5 mile Library line underwent "minimal" rehabilitation at a cost of $1 million to allow use of the line by LRVs. This suggests that use of different design standards, than were used on Stage I, might significantly reduce the projected $300 million cost of a Stage II LRT line (Biehler, 1989).

Figure 6-9. Spine Line LRT Alignments and Stations



In 1985 PAT hired Baker Engineers to conduct a study of the "Spine Line Corridor." The consultants developed year 2000 estimates of patronage, revenue, capital and operating cost for several alternatives including:

1. Do nothing;

2. Transit System Management (TSM), including actions such as one-way streets, exclusive bus lanes and intersection channelization; and

3. LRT - the same mode as in the Stage I of the South Hills LRT.

The TSM alternative developed by Baker Engineers would extend existing or create new exclusive bus lanes on three streets (Sandusky, Anderson and Federal) on the North Side; four streets (Fifth, Forbes, Fort Duquesne Boulevard and Wood St.) in the downtown; and three streets (Forbes, Fifth and South Bellefield) in the eastern portion of the corridor. The TSM alter-

native would provide additional bus service between Oakland and downtown Pittsburgh using the East Busway. The LRT alternative would extend the Stage I LRT from the downtown subway westward to the North Side, across the Sixth Street Bridge, and then under Allegheny Center to Allegheny Community College. The eastern line would extend from the downtown subway to Oakland and the Cathedral of Learning at the University of Pittsburgh, and then follow under Forbes Avenue to Carnegie-Mellon University and continue on to Shady Avenue in Squirrel Hill.

A "major" finding of the Baker study (1985, p. xxii) was that the downtown subway and stations had sufficient capacity to accommodate projected demand from the completed South Hills LRT project (both Stages I and II) and from the proposed Spine Line LRT. The study which concluded the Spine Line LRVs would be able to use the South Hills LRV maintenance facility, also suggested that the Spine Line LRT would spread the capital costs of the South Hills LRT over a larger patronage base and thereby reduce the per unit capital cost of the facility. The consultants offered this reduction in average costs as an important benefit of the Spine Line LRT.

The Baker Engineers' study found, however, that even if the downtown subway and the South Hills LRV maintenance facility could accommodate projected Spine Line LRT services, the LRT alternative had much greater capital costs (i.e. without consideration of the subway or LRT maintenance facility sunk costs) than the TSM alternative. Incremental capital costs for the Spine Line LRT alternative were projected to be $310 million (1989 dollars) , while projected capital costs for the TSM alternative were only $21 million in 1989 dollars. At the same time the consultants found that the TSM and several LRT alternatives would have similar performance and ridership. Projected annual ridership for the Spine Line LRT was only about three percent higher than projected TSM ridership. Projected annual fare revenues and operating costs for the LRT alternative were only one percent higher than the TSM alternative.

Since projected ridership and revenues and operating costs per passenger for TSM and the far more costly LRT alternative were so similar, it is somewhat surprising that the Baker report recommended further study of the LRT proposal. The authors of the Baker report based their recommendation for further study of the LRT alternatives on two principal arguments. First, they argued, without any supporting evidence, that providing LRT service to Oakland and other areas serviced by a LRT Spine Line "would contribute to the continued development of the area" (Baker, 1985). Second, they advanced the misleading and economically incorrect argument that the proposed Spine Line LRT could "share" the sunk capital costs of the downtown subway and the South Hills LRV maintenance facility.* These seem rather flimsy justifications for a project that would have capital costs nearly 15 times as large as the TSM alternative.

Highway HOV Plans

Compared to Washington D.C., Houston, and the San Francisco Bay Area, the Pittsburgh metropolitan area has relatively few HOV facilities operational or in the planning stage. One highway HOV lane has recently been opened (Fall 1989) as part of a I-279/I-579 highway expansion project, and there are several proposals for HOV facilities in the downtown area.

* Economists are unanimous in the view that only the incremental benefits and costs of proposed investments are pertinent in deciding relative project merits. Sunk cost, i.e. already committed capital outlays, have no bearing.

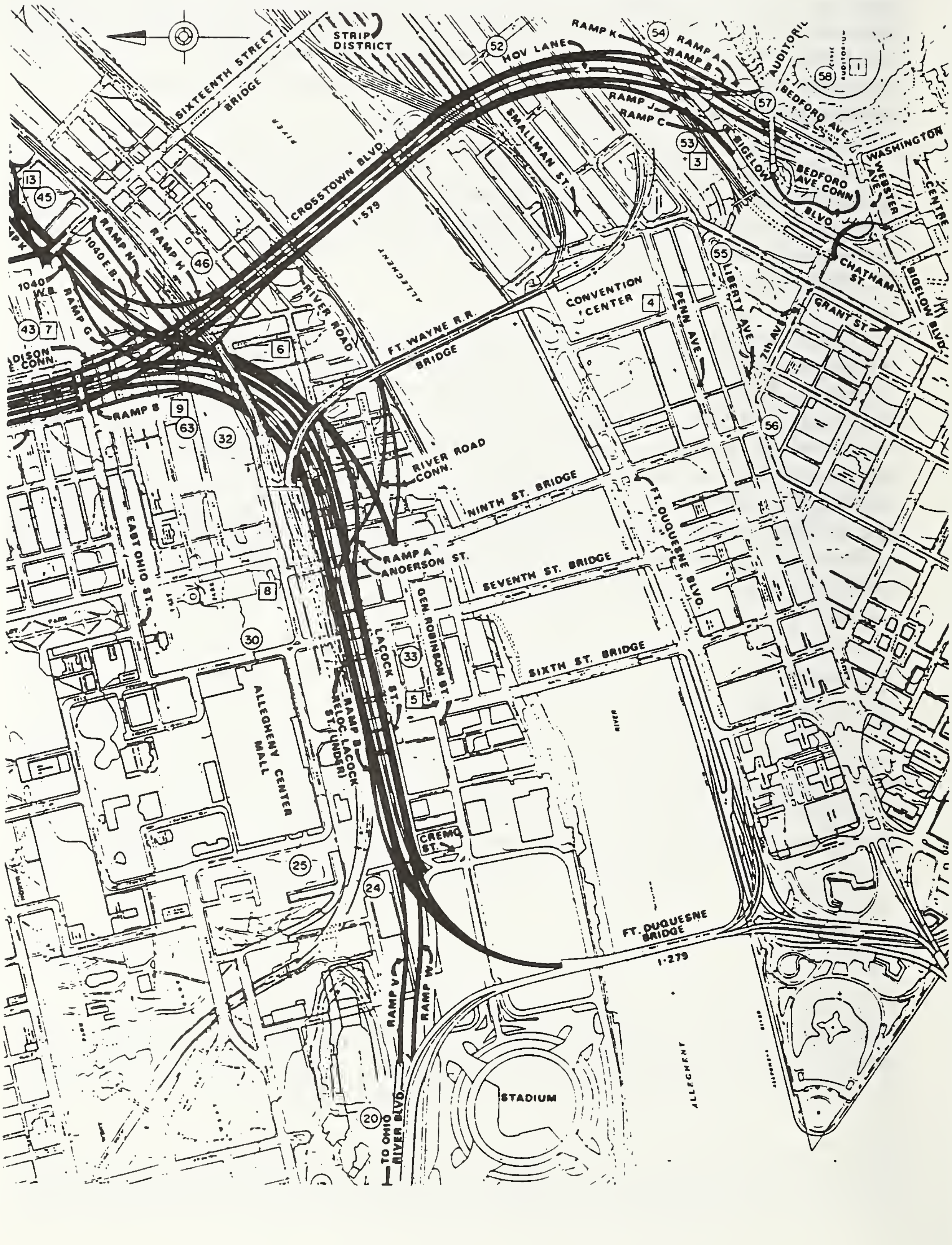
There are seven primary roadway approaches to downtown Pittsburgh: the Squirrel Hill Tunnel, the Fort Pitt Tunnel, the West End Bridge, Ohio River Boulevard, Route 28, the Liberty Bridge, and East Street. Of these seven, East Street, with only a single traffic lane in each direction, is the most obvious and serious bottleneck. The region's traffic and highway engineers have thus concluded that additional capacity must somehow be provided along East Street to ease congestion. The most appealing proposal would make East Street a two-lane reversible HOV facility with direct connections to I-279. Additional proposals include an HOV lane to provide access to the Ninth Street Bridge, and HOV ramps to the Civic Arena and the Three River Stadium parking areas (see Figure 6-10).

PennDOT is responsible for the planning, design, and implementation of HOV projects in the greater Pittsburgh area. PAT has not been as active in HOV projects as they have been on busway planning and operations. PAT's philosophy has been that they will use HOV facilities when they reduce transit trip times. For example, in October 1989 PAT began bus operations on the I-279/I-579 highway HOV lanes.

PAT's relative lack of involvement with HOV projects, compared to its strong commitment to the South and East Busways, seems to be territorial in part. While PAT owns and operates the busways, it would be nothing more than a user of HOV facilities, which are owned and operated by PennDOT. Of course, it is also possible that the proposed facilities would benefit PAT's operations very little and that PAT has determined that it would not materially affect PennDOT's actions even if PAT made a major commitment to participating in the planning and design of the region's HOV facilities. Even so, experience in other cities and recent changes in behavior suggest that PAT's former view may have been mistaken and that substantial gains may be obtained in this way. There are indications, moreover, that PAT has begun a more active involvement with PennDOT and with other regional transportation agencies in HOV planning and implementation.

Figure 6-10.

Proposed HOV Lanes In Downtown Pittsburgh



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Chapter 7. The Shirley and Other Bus-HOV Facilities in the Nation's Capital

Introduction

Three of North America's most significant and innovative HOV facilities are located in the Washington, D.C. metropolitan area. The Shirley Highway HOV express lanes, the I-66 HOV Parkway, and the I-95 diamond lane were implemented to encourage carpooling and more extensive use of bus transit during peak periods. All three schemes, see Figure 7-1, are used principally by Northern Virginia residents for peak period travel to and from work, and were designed to complement the region's extensive rail rapid transit system. Both the Shirley Highway and the I-66 HOV Parkway, for example, provide park and ride facilities with convenient access to Metrorail stations.

While relatively unnoticed (except by Northern Virginia commuters), Virginia's HOV facilities carry nearly 60,000 persons per day during the morning peak period. Even so, these important commuter facilities have been eclipsed by Washington D.C.'s impressive, but costly rapid rail system.

Since it began operations in 1976, Metrorail has attracted the lion's share of attention of both transport planners and the public, not all of it favorable (Deich and Wishart, 1988). During 1987, Washington Metropolitan Area Transit Authority's (WMATA's) 160 mile Metrorail system carried just over 93,000 persons per day across the District cordon, 27,000 were carried during the AM peak from Northern Virginia (MWCOG, 1987). The Shirley Highway and I-66 HOV lanes, however, carried 45,000 inbound passengers per day across the District of Columbia cordon from Northern Virginia, two-thirds more commuters than the far more extensive and far more expensive Metrorail system (MWCOG, 1987). While it is not easy to allocate the joint cost of HOV facilities between them and the rest of the highway, it is nonetheless clear that the combined capital cost of the Northern Virginia HOV lanes is but a small fraction of the capital cost of the Metrorail system. (A more detailed discussion of these capital costs is presented at the end of this chapter and in Chapter 15.)

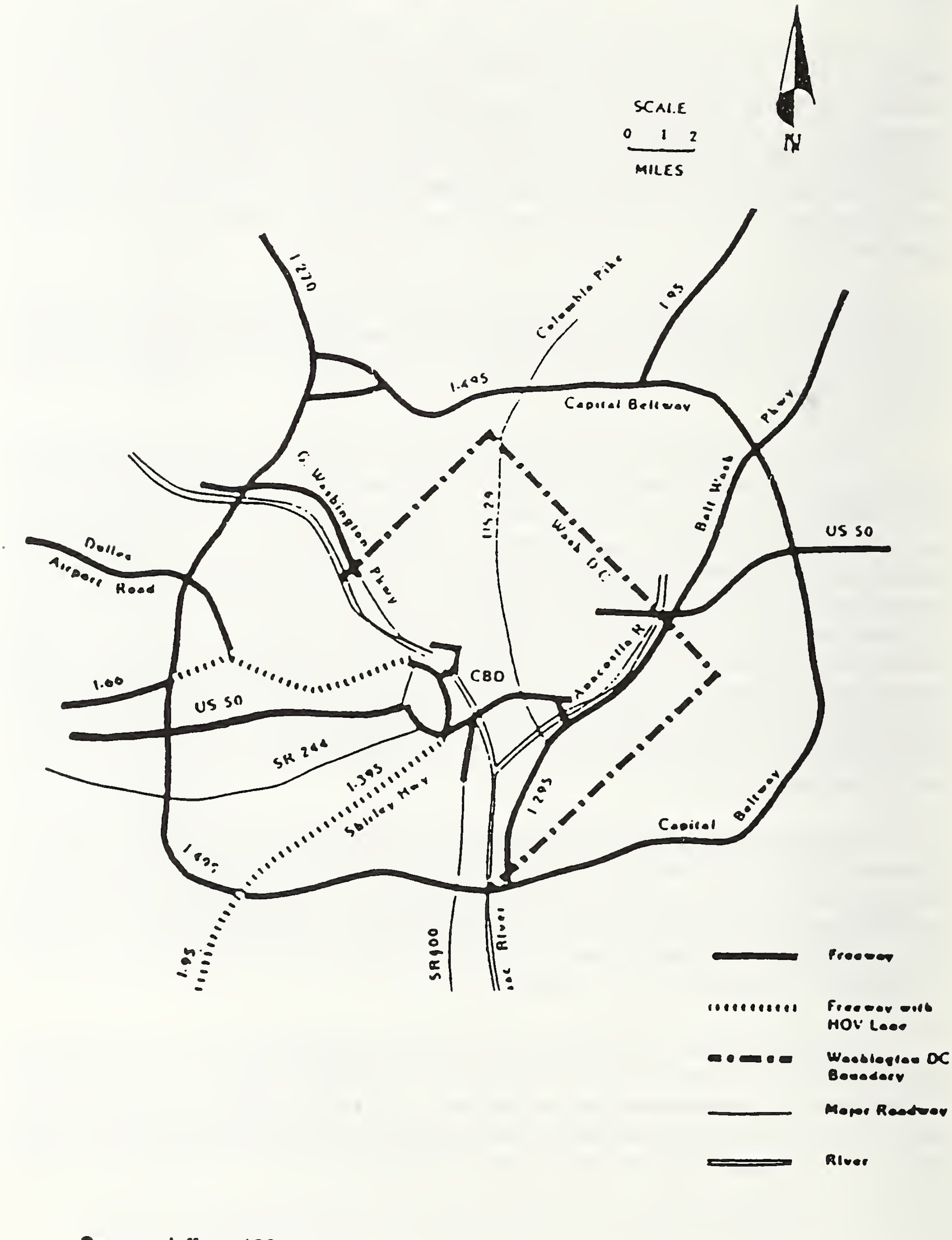
All three Northern Virginia HOV facilities were built as part of larger corridor highway improvement projects and have been implemented in stages, with significant modifications over time. The Shirley Highway express lanes, for example, were originally designed as reversible, general traffic (not restricted to HOV use) express lanes and were built as part of a highway widening project. This project converted the Shirley Highway from a 4-lane, urban arterial (two lanes in each direction) to an 8-lane freeway.

The Shirley Highway is the oldest and most intensively used of the three HOV facilities in the Washington, D.C. metropolitan area. A segment of the Shirley Highway's two physically segregated, reversible express lanes began operating in September, 1969 as an exclusive bus-lane.* It was more than a decade later, in 1982, before the 4-lane (2 lanes in each direction) I-66 HOV peak period, peak direction HOV Parkway was opened to traffic. The northbound section

* The southern-most portion first opened as a bus-only facility, while northern sections were still under construction.

Figure 7-1.

Northern Virginia Highways to Washington, D.C.



Source: Jeffrey, 1987, p.78.

of the I-95 median diamond lanes, which is essentially an interim, low cost extension of the Shirley Highway express lanes, opened in December 1985; the southbound section opened in September 1986.

As the data in Table 7-1 reveal, the Shirley Highway HOV lanes, the I-66 HOV Parkway, and the I-95 diamond lanes served an average of 58,600 persons during the AM peak period (6-9 AM) in May 1988 and nearly 30,000 persons during the AM peak hour. Average auto occupancy for the HOV lanes was 4.1 persons per vehicle as compared to a 1.2 to 1.3 persons per vehicle in the general freeway lanes. During the AM peak period, the three HOV facilities carried an average of 4,186 persons per lane per hour, a figure well in excess of the 1,200-2,500 persons per lane hour that were carried by each peak direction general purpose freeway lane in the corridor during peak hours.

All three HOV facilities, and particularly the Shirley Highway HOV express lanes are heavily used by buses. As Table 7-1 indicates, over 500 buses carried nearly 19,000 passengers during the morning peak period on the three Northern Virginia HOV facilities in May 1988. While bus riders accounted for 32 percent of all HOV lane users, their buses comprised only four percent of all vehicles using the HOV lanes. Fifty-nine percent of the buses using the three Northern Virginia HOV facilities during peak periods were operated by WMATA, the remainder were provided by other operators (Virginia DOT, 1988).

Table 7–1. Northern Virginia to Washington D.C. AM Peak Period and Peak Hour Person and Vehicle Trip by Facility, May 1988

Time and Facility	Vehicles Total	Vehicles Bus	Persons Total	Persons Bus	Per Lane Hour Vehicles	Per Lane Hour Persons	Auto Occupancy Rates
Peak Hour (6:45–7:45AM)							
Shirley Express Lanes	2,279	179	16,526	6,265	1,140	8,263	4.9
I–66 HOV Lanes	1,638	19	5,795	665	819	2,898	3.2
I–95 HOV Diamond Lane	1,516	42	7,153	1,470	1,516	7,153	3.9
Total (5 HOV lanes)	5,433	240	29,474	8,400	1,087	5,895	4.1
Peak Period (6–9AM)							
Shirley Express Lanes	4,835	402	32,908	14,070	806	5,485	4.2
I–66 HOV Lanes	3,945	49	11,876	1,715	789	2,375	2.6
I–95 HOV Diamond Lane	3,819	81	13,815	2,835	1,273	4,605	2.9
Total (5 HOV lanes)	12,599	532	58,599	18,620	900	4,186	3.3

Note: (1) All figures include buses and lane violators.
(2) I–66 HOV peak period is 6:30–9 AM.
(3) Total peak period lane hours are 6 for the Shirley Highway (3 hours times 2 lanes); 3 for the I–95 HOV diamond lanes (3 hours times 1 lane); and 5 for the I–66 HOV parkway (2.5 times 2 lanes),

Source: Virginia Department of Highways and Transportation, May, 1988.

During May 1988, the Shirley Highway HOV express lanes carried close to 33,000 AM peak period (6-9 AM) commuters, the northbound (inbound) I-95 median diamond lane carried 13,800, and the 2-lane I-66 HOV Parkway carried nearly 12,000. Of these peak period person trips, 14,070 (48 percent) of Shirley Highway, 2,835 (21 percent) of I-95, and 1,715 (14 percent) of I-66 commuters were by bus. The large majority, 98 percent, of WMATA HOV bus riders in the corridor used the Shirley express lanes; the I-66 HOV lanes have limited WMATA service, and most areas served by the I-95 diamond lanes are outside the WMATA service area.

The Shirley Highway Reversible HOV Lanes

The Shirley Highway is the only highway in North America which provides two reversible HOV lanes within an urban freeway. The Houston transitways, for example, have one reversible lane, and the El Monte Busway provides one lane in each direction. The Shirley Highway's two express lanes are located in the highway median and are barrier separated. The most common configuration consists of two express lanes in the center of an 8-lane freeway, between six general traffic lanes (three in each direction). In some areas there are four general traffic lanes in each direction, and from Eads Street north the highway has four express lanes (two lanes in each direction); these lanes are not reversed and do not give priority to HOVs, they are open to all two-way traffic at all times.

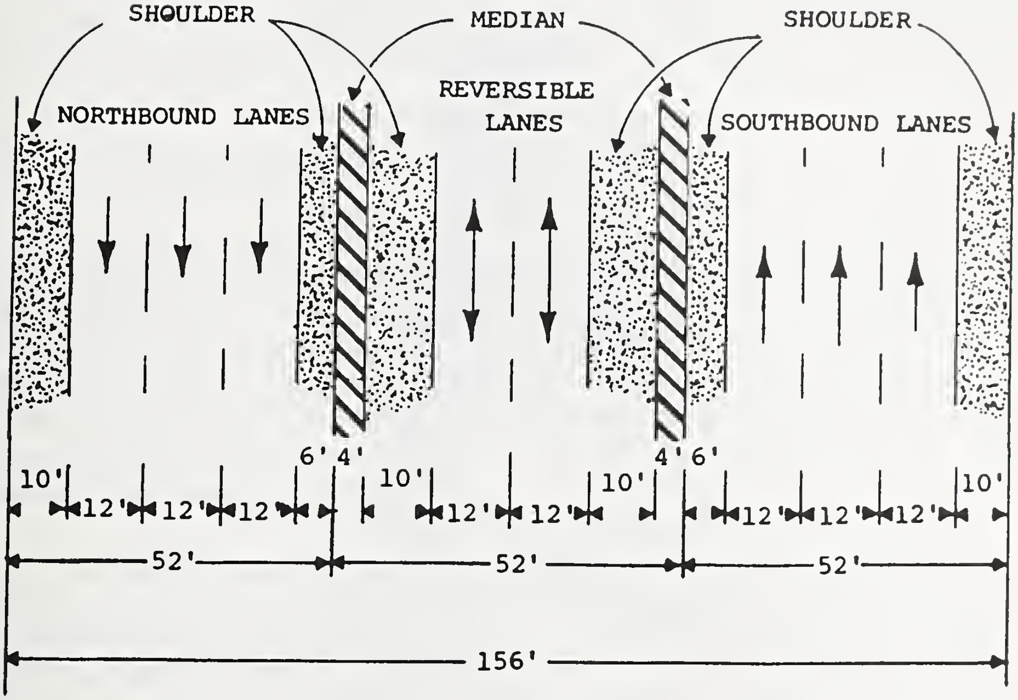
During the nearly 20 years the Shirley Highway HOV lanes have been in operation, carpoolers and bus passengers using the facility during peak periods have saved approximately 15-20 minutes per trip relative to users of the adjacent general traffic lanes.* During both the AM and PM peak periods traffic moves freely on the HOV lanes at speeds near the posted 55 mph limit, while speeds in the adjacent general traffic lanes average 19 to 33 mph during the AM peak period and 27 to 49 mph during the PM peak period (VDOT, 1988; Oak Ridge National Lab., 1985).

Figure 7-2 provides a typical cross-section of the Shirley Highway showing the relationship of the express lanes to the regular lanes. The express lanes are 12 feet wide with two 10 foot shoulders on each side, a design feature that makes it possible for disabled vehicles to use either shoulder. There is also a double-faced guard rail on each side of the express lanes with breaks to permit police cars, wreckers, and other emergency vehicles to enter and leave the express lanes. The general traffic lanes are also 12 feet wide with one 10-foot and one 6-foot shoulder in each direction.

The Shirley Highway's barrier separated, median HOV lanes currently extend for 12 miles. Buses and carpools enter and leave the Shirley Highway express lanes at several T-ramps and slip ramps. As Figure 7-3 indicates, there are six northbound entrances and six southbound exits along the 12 mile stretch of the Shirley Highway HOV lanes. Similarly, there are six southbound exits and 4 northbound entrances. The northern terminus of the Shirley Highway HOV lanes is just north of the 14th street bridge in the District of Columbia. The southern terminus and northbound entry points are at a slip ramp at the I-95, I-395, and Beltway (I-495) interchange.

* Travel times for general traffic lane users also declined when carpools began using the Shirley Highway express lanes. Nonetheless, travel times for vehicles in the general traffic lanes remained much longer than for those using the HOV lanes.

Figure 7-2. Typical Cross-Section of Shirley Highway



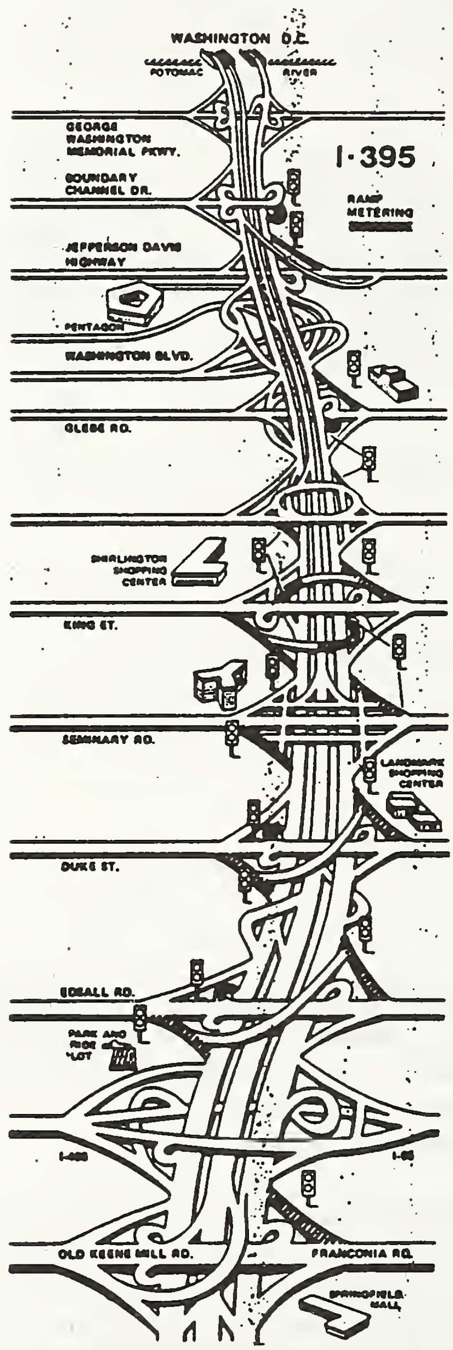
Source: JHK & Associates, 1986.

The Shirley Highway HOV lanes operate one-way northbound between 11 PM and 11 AM and one-way southbound between 1 and 8 PM. Use of the express lanes had been restricted to vehicles with four or more (4+) occupants from 6-9 AM and 3:30-6 PM; as an experiment to determine the best corridor occupancy level, on January 3, 1989 the occupancy requirement was lowered to three or more (3+).

The lanes are closed to all traffic from 8 to 11 PM and between 11 AM and 1 PM to allow for reversing the direction of traffic flow on the facility. The segment from Turkeycock to Springfield is an exception to these occupancy rules; during the evening peak period it is open to all southbound traffic. This is because there is limited demand by carpools and buses and also because the adjacent general traffic lanes are heavily congested. There are no restrictions on the express lanes outside of the AM and PM peak periods. As noted previously, from Eads Street north, four median lanes (two lanes in each direction) accommodate bi-directional general traffic at all times.

Figure 7-3.

Shirley Highway Interchanges



Source: Arnold and Lantz, 1985, G-3.

There is a permanent park and ride lot at Huntington Station directly off the Shirley Highway express lanes, where commuters can transfer to Metrorail trains.* The Huntington Station park and ride lot is at the end of the Metrorail Yellow Line and has kiss and ride platforms and spaces for 150 vehicles. In addition, several area shopping centers along the Shirley Highway and within walking distance to Metrorail stations are used as park and ride facilities; in some instances there are formal arrangements between WMATA and the centers to permit commuters to use the lots, in other instances the lots are used informally or illegally.

Development of the Shirley Highway HOV Lanes

Completion of the Shirley Highway HOV lanes took nearly 10 years between the start of construction and full operation, and required extensive inter-agency cooperation. The Federal Highway Administration (FHWA) and UMTA cooperated in a then unprecedented manner to demonstrate that joint use of freeways by private cars and mass transit could provide cost-effective increases in peak hour capacity. Implementation of the Shirley Highway HOV lanes also required the cooperation and active support of various state and local agencies, including the Virginia Department of Highways and Transportation (Virginia DOT) and the District of Columbia Department of Highways and Traffic.**

The program to up-grade the Shirley Highway from a 4-lane controlled access highway to an 8-lane expressway began in 1964. The HOV express lanes became operational in increments, beginning with the southern most sections. In September 1969, the first 4.8 miles of HOV lanes from just south of I-495 and the Shirlington interchange to Edsall Road were opened to buses during peak periods.

When the Shirley Highway express lanes were made available to buses, it became the first time that a part of an interstate highway had been dedicated to exclusive bus use. The initial 4.8 miles of exclusive bus lane saved bus commuters from Northern Virginia 12 to 18 minutes per trip. Bus ridership on the Shirley increased dramatically from 3,800 AM peak period riders in 1969, when the facility first opened, to 4,500 in 1970, and to 9,000 by 1971.***

In April 1971, the permanent Shirley Highway HOV lanes were extended to their present 12 mile length, including bus-only lanes on the 14th Street Bridge (Figure 7-3). At this time, the Shirley Highway project also became part of a joint FHWA and UMTA "Bus-on-Freeway" demonstration project. The project's goal was to determine how suburban commuters would respond to high-speed, quality bus service. Federal funding enabled AB&W Transit to purchase 90 new buses and to satisfy most of the increase in demand induced by the significant reductions in bus

* Metrorail's Yellow Line first began serving Northern Virginia in December, 1983.

** Other agencies with major roles in planning, developing, maintaining, and operating the Shirley Highway HOV lanes include the Northern Virginia Transportation Commission (NVTC), the local grantee of some of the federal money; the Metropolitan Washington Counsel of Governments, early planners of the project; AB&W Transit Company; and Washington Metropolitan Area Transit Authority (WMATA), AB&W Transit's successor.

*** Between September 1970 and April 1971, buses on the Shirley busway were also able to use a 1.5 mile single lane (18 feet wide) segment of temporary buslane which bypassed a segment of roadway undergoing construction and experiencing severe congestion. This segment extended from the end of the permanent express lanes at Shirlington to the north end of Glebe Road.

trip times. The demonstration project also paid for the construction of the park and ride lot at Huntington Station.

Between 1970 and 1975, bus service and ridership on the Shirley Highway express lanes increased dramatically. AB&W Transit (and later WMATA) more than doubled the number of Shirley Highway AM peak period bus trips, from 95 to 190. As a result of these increases in bus frequencies and time savings, AM peak period bus ridership increased from 4,500 in 1970, to 13,500 in 1973, and to over 16,000 in November 1974.* The 90 new buses purchased through the demonstration project proved to be too few, however, and the growth in Shirley Highway bus ridership appears to have been limited by bus availability, particularly during the 1974-75 oil crisis (Smith and Locke, 1975, p.V-1).

Even with greatly increased bus service and ridership, the two Shirley Highway exclusive bus lanes were being used well below their effective capacity. In December 1973, a portion of the Shirley express lanes were converted from busway to a bus/carpool facility. Vehicles with four or more occupants were allowed to use the nine mile segment of HOV lanes between Springfield and Washington Boulevard. In contrast to the Houston experience, discussed in Chapter 10 , where carpool use of the transitway was <u>not</u> anticipated, the opening of the Shirley Highway express lanes to 4+ carpools had been planned from the inception of the Shirley Highway widening project (Smith and Locke, 1976, p.III-7). Exclusive bus use of the express lanes during 1969-1973 was viewed as a temporary measure, while the roadway was being rebuilt and additional slip and T-ramps were being constructed.

Before carpools were allowed to use the facility, fewer than 350 vehicles (all buses) used the express lanes during the AM peak period. After 4+ carpools were authorized, the total number of vehicles using the lanes during the AM peak period increased sharply to 1,450, including 1,100 carpools. Even these much higher volumes, however, were well below levels that would maintain level of service C or better, the criterion used by Virginia DOT in managing the facility (Christiansen, 1985 p.38).

It is difficult to evaluate the effects of Virginia DOT's decision to allow carpools to use the Shirley express lanes on bus ridership, since the introduction of carpools coincided with the first oil shock and the "Bus-on-Freeway" demonstration project. The available evidence suggests, however, that the decision to allow 4+ carpools on the facility had very little effect on bus ridership.** Ridership on Shirley Highway buses entering south of Shirlington during the AM peak period, for example, actually increased from 9,773 in November 1973 (the month before 4+ carpools were allowed to use the lanes) to 11,494 in October 1974 (Smith and Locke, 1976, p.V-3).

Prior to October 1975, carpools were not allowed to use three of the six entrances to the Shirley Highway express lanes (the slip ramps at I-95 south of Route 644, Old Keene Mill Road, and Turkeycock) and all carpools were required to exit at Washington Boulevard. Starting in October 1975, however, as Shirley Highway construction neared completion, 4+ carpools were permitted to continue northward across the 14th Street Bridge. Then, in stages between

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* Express lane bus ridership figures include AB&W Transit, WMATA and private carriers.

** At the present time, conclusive evidence on the effect of lowering the carpool requirement to 3+ is not available. The Virginia Department of Transportation is collecting data on all three HOV facilities to update their data base and when this new data is available it should be possible to draw preliminary conclusions on the effect of the January 3, 1989 changes.

November 1975 and October 1976, all of the segments of the express lanes and interchanges were opened to carpools. There is no evidence that permitting carpools on all portions of the facility caused any significant delays to buses or any safety problems. This is due to the fact that the Shirley Highway express lanes and ramps were designed for bus and carpool use from the outset and the criterion used to define carpools kept their numbers well below the facility capacity.

As the data in Figure 7-4 reveal, total Shirley express lanes person trips (buses plus carpools) during the AM peak period grew from 4,500 in 1970 to 40,300 in 1983. Not surprisingly, the most significant increases came immediately after the facility was opened to 4+ carpools. After carpools began using the two express lanes in 1973, AM peak period person trip volumes increased by 50 percent from 13,500 in 1973 to 20,000 in 1974. Between 1973 and 1981, moreover, the number of vehicles using the facility increased more than four-fold from 350 to 1,450, with virtually all of the growth consisting of newly admitted carpools. As indicated in Table 7-2, by May 1988, carpools accounted for 57 percent of person trips and 92 percent of vehicles using the Shirley Highway HOV lanes.

Starting in the early 1980's, the number of persons using the Shirley Highway HOV lanes during the AM peak period declined steadily from 43,500 in 1981, to below 35,000 in 1983, and to 32,900 in 1988. These declines were by design in large part, and are explained by several factors including the opening of the I-66 HOV Parkway in 1984, the diversion of many bus riders to Metrorail, and a restructuring of Northern Virginia bus routes to feed the Metrorail Yellow Line, which was completed in 1983.

Figure 7-4. Shirley Highway HOV Lanes Person Trips (1970-1983)

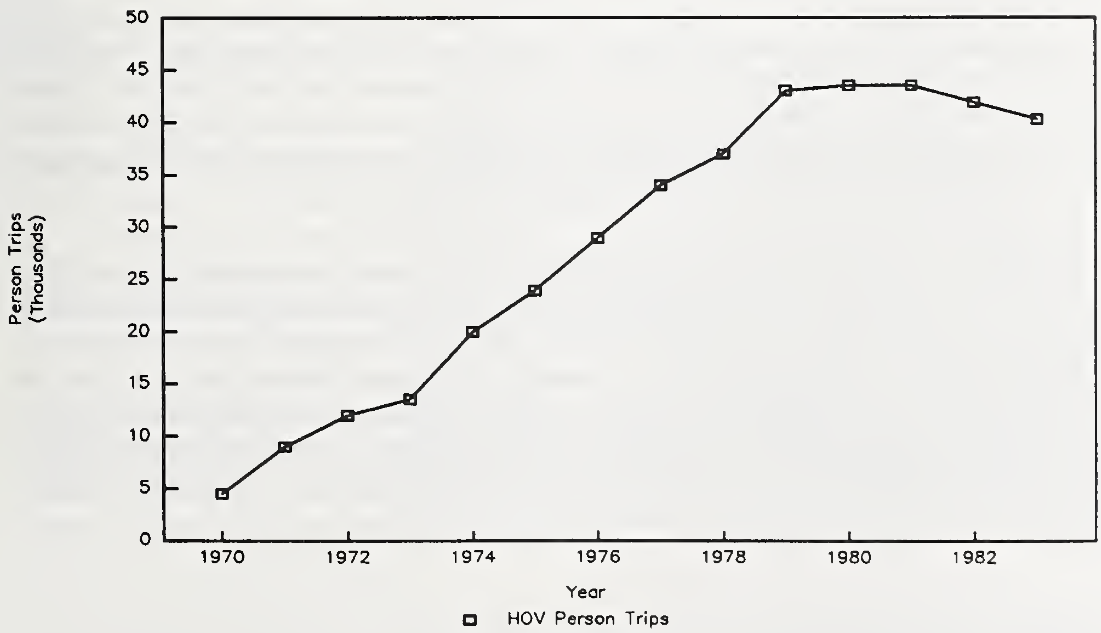

Table 7–2. Shirley Highway (I–395) Express and General Traffic Lanes
AM Northbound Peak Hour and Peak Period Vehicle and
Passenger Volumes, May 1988

Time and Facility	Vehicles	Persons	Average Occupancy	Per Lane Hour Vehicles	Per Lane Hour Persons
Peak Hour (6:45–7:45AM)					
Express Lanes					
Buses	179	6,265	35.00	90	3,133
Carpools	2,100	10,261	4.89	1,050	5,131
Total Express Lanes	2,279	16,526	7.25	1,140	8,263
General Traffic Lanes	8,398	10,738	1.28	2,100	2,685
Entire Highway	10,677	27,264	2.55	1,780	4,544
Peak Period (6–9AM)					
Express Lanes					
Buses	402	14,070	35.00	67	2,345
Carpools	4,433	18,838	4.25	739	3,140
Total Express Lanes	4,835	32,908	6.81	806	5,485
General Traffic Lanes	23,571	29,351	1.25	1,964	2,446
Entire Highway	28,406	62,259	2.19	1,578	3,459

Note: (1) All express lane figures include buses & lane violators.
(2) Total peak period lane hours are 6 for the express lanes (3 hours times 2 lanes) and 12 for the general traffic lanes (3 hours times 4 lanes – the maximum number of general traffic lanes found on I–395.
Source: Virginia Department of Highways and Transportation, May, 1988.

The number of transit buses serving the corridor has decreased each year since 1977. As Metrorail was being completed, WMATA reduced frequencies on most Northern Virginia commuter bus routes and restructured many others to feed the Metrorail stations (MWCOG, 1987, p.13). Completion of the Yellow Line and the extension of the Orange Line (completed in 1986) diverted additional Shirley Highway bus riders to rail (Ibid, p.33).

Declines in peak period person trip volumes and a growing perception that the Shirley Highway express lanes were underutilized led Virginia DOT to open the Shirley Highway HOV lanes to all vehicles during off-peak periods in April 1985. This change was mandated by federal legislation introduced by Republican congressmen Frank Wolf and Stanley Parris, whose districts, not surprisingly, were located in Northern Virginia. The new regulations governing Shirley Highway HOV use, as well as those relating to use of the I-66 Parkway, were first implemented as part of a one year demonstration and then made permanent the following year (Bauer, 1983, B-7).*

* The same legislation also changed I-66 HOV requirements from 4+ occupants to 3+ and reduced the restricted period hour on I-66 from 6:30 to 9 AM and 3:30 to 6:30 to 7 to 9 AM and 4 to 6 PM.

Permitting low occupancy vehicles to use the Shirley Highway express lanes during off-peak periods induced some drivers of low occupancy vehicles to shift from peak period use of the general traffic lanes to off-peak use of the HOV lanes during time intervals just before or after the peak periods, i.e. 9-10 AM and 6-7 PM. The most dramatic decline in HOV use of the express lanes occurred in the year immediately following the implementation of the new policy. During this one year period, i.e. Fall 1984 to Fall 1985, the number of 4+ carpools using the Shirley express lanes during the extended peak periods (6-10 AM) and (3-7 PM) declined approximately 15 percent. In addition, the carpool modal share of all person trips declined from 28 percent to 23 percent during the AM peak period and from 18 percent to 14 percent during the PM peak period.

In the first year after LOVs were allowed to use the Shirley Highway express lanes during off-peak periods, the number of vehicles using the lanes during the AM peak period (6-10 AM) increased by nearly 75 percent, from 4,002 to 6,955, while person trips increased by only 11 percent, from 22,033 to 24,364, and average vehicle occupancy rates fell from 5.52 to 3.50. Similar declines in vehicle occupancy occurred during the PM peak period (JHK, 1986, p.37). Bus ridership appears to have been unaffected by the decision to open the HOV lanes to LOVs during off-peak periods, as AM peak period (6-10 AM) bus ridership on the Shirley actually increased by 9 percent from 12,842 in Fall 1984 to 13,970 in Fall 1985 (JHK, 1986, p.40).

Opening the express lanes to all vehicles during off-peak hours significantly increased HOV lane person trip volumes, and resulted in some improvement in travel conditions for users of the general traffic lanes (JHK, 1986, p.1). Increases in the number of vehicles using the express lanes in the transitional hours before the peak period restriction appeared to have had little impact on express lane operations. This was not true, however, after the restricted period. During the unrestricted shoulder periods, i.e. 9-10 AM and 6-7 PM, a surge of low occupancy vehicles into the express lanes often led to serious congestion. Indeed, speeds in the express lanes frequently fell to levels below those in the adjacent general traffic lanes. The most serious congestion problems arose at the end of the PM restricted period, i.e during the half hour between 6 and 6:30 PM (JHK, 1986, p.70).

Those responsible for managing the Shirley Highway have been reluctant to lower the minimum carpool occupancy to three persons. Though at one point, local area transportation officials feared a 4+ criteria for carpools was too restrictive and would seriously inhibit carpool use. Local drivers, however, have been quite resourceful in forming and maintaining carpools.* As in the San Francisco Bay Area (Chapter 4), casual carpooling, the opportunistic formation of carpools by passengers at bus stops and near entry ramps to the express lanes, is pervasive.

The recent (January 1989) change to 3+ carpool designation on the Shirley Highway express lanes has reduced vehicle occupancy levels. Virginia DOT took vehicle counts on I-395 north of 20th Street in Arlington on December 14, 1988 and February 14, 1989. The number of vehicles in the morning peak period increased by 35 percent, from 2,487 to 3,367, while the number of passengers rose by only 8 percent from 18,831 to 20,396. The preliminary

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* During a recent trip to Washington a good friend offered to take one of the authors and an associate to Dulles Airport so that he could use I-66 HOV Parkway. When he learned they were staying overnight, he instead joined them for an early dinner so that he could use I-66 as a single occupant after the 3+ restriction expired.

data indicates a drop in vehicle occupancy from 7.6 persons per vehicle to 6.1, a decline of 25 percent. The sources of this decline include a shift from bus to carpooling, fewer passengers in already existing carpools, and an increase in the number of violators.*

Carpool and Bus Ridership

As Table 7-2 indicates, nearly 33,000 commuters were carried by the two Shirley Highway express lanes in the morning peak period (6-9 AM) during May 1988. As these data reveal, the two express lanes carry more commuters in significantly fewer vehicles than the (3-4) general purpose freeway lanes. During the morning peak period, peak direction general traffic lanes carry 12 percent fewer people in approximately four times the number of vehicles. During peak periods, moreover, the HOV lanes serve 125 percent more passengers per lane per hour than the general traffic freeway lanes 5,584 compared to 2,446. Heavy traffic in the general traffic lanes result in level of service F during the peak period, while the HOV lanes operate at level of service C or better (Virginia DOT, 1988).

During the peak hour (6:45 - 7:45 AM), the difference in the number of persons served by the Shirley Highway HOV and general traffic lanes is even more pronounced. The Shirley express lanes average nearly 8,300 persons per lane during the peak hour, while the general traffic lanes average fewer than 2,700. Thus, the two Shirley Highway HOV lanes carry more than 50 percent more passengers than the adjacent four general traffic lanes during the morning peak hour.

The high passenger volumes achieved by the Shirley express lanes during the peak period are attributable in large part to the fact that large numbers of buses and bus commuters use the facility. As the data in Table 7-2 indicate, 63 percent of the more than 16,500 persons using the two HOV lanes during the AM peak period in May 1988, rode buses; these buses comprised only eight percent of vehicle volume.** A smaller fraction, i.e. 57 percent, of peak hour HOV lane users rode the bus. This somewhat anomalous result is explained by the fact that Virginia DOT defines the peak hour in terms of vehicle use rather than person volumes.

The I-95 Diamond Lanes

In December 1985, Virginia DOT implemented six miles of median (left shoulder) HOV diamond lane on I-95 in the northbound direction feeding into the Shirley express lanes at the Beltway (I-495) interchange. In September 1986 a diamond lane in the southbound direction on the same segment of I-95 was opened. Use of the I-95 diamond lanes, shown in Figure 7-1, was restricted to vehicles with 4+ occupants until January 3, 1989, when it was reduced to 3+. This change made the I-95 carpool criterion consistent with that used for the Shirley Highway

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* The Virginia DOT has begun using a voluntary program, project HERO, in an attempt to reduce the number of violators. The program is based on a similar program used in Seattle, which is described in Chapter 9 of the report. A reported violation does not lead to a fine, but to a written warning. No legal action is taken against a driver until a violation has been observed by a state trooper.

** Of the 402 bus trips using the Shirley Highway HOV lanes during the typical peak period, 76 percent are operated by WMATA.

HOV lanes. The I-95 diamond lanes originally operated during the same hours as the Shirley Highway HOV lanes (6-9 AM and 3:30-6 PM), however, in 1987, the I-95 diamond lane PM peak period hours were extended to 7 PM to help clear carpools from the Shirley Highway HOV lanes.

During May 1988, over 13,800 persons per day in 3,800 vehicles used the I-95 northbound diamond lane during the AM peak period (6-9 AM). As Table 7-3 reveals, average carpool occupancy rates during the AM peak period i.e. 2.94, were less than the carpool minimum size, which in 1988 was four. The reason was that more than half the peak period users of the diamond lane (56 percent) were violators. As a result, the I-95 diamond lane operate at level of service D throughout the peak period. The intensive use of the I-95 diamond lane during the AM peak period, nearly 1,300 vehicles per lane per hour as compared to 800 per hour on the Shirley express lanes, is explained by high violation rates, and by the fact that there is only one I-95 diamond lane as compared to two Shirley Highway HOV lanes.

During the AM peak hour (6:30 - 7:30 AM), violations in the diamond lane drop to 34 percent and average carpooling occupancy rises to 3.9. Unfortunately, because of high vehicle volumes, i.e. an average of more than 1,500 per hour, the lane operates at a level of service D. If violations could be eliminated or significantly reduced, the diamond lane would function at a

Table 7–3. I–95 HOV and General Traffic Lanes AM Northbound Peak Hour and Peak Period Vehicle and Passenger Volumes, May 1988

Time	Vehicles	Persons	Average Occupancy	Per Lane Hour Vehicles	Per Lane Hour Persons
Peak Hour (6:30–7:30 AM)					
HOV Diamond Lane					
Buses	42	1,470	35.00	42	1,470
Carpools	1,474	5,683	3.86	1,474	5,683
Total HOV	1,516	7,153	4.72	1,516	7,153
General Traffic Lanes	4,320	5,172	1.20	2,160	2,586
Shoulder	989	1,082	1.09	989	1,082
All Lanes	6,825	13,407	1.96	1,706	3,352
Peak Period (6–9 AM)					
HOV Diamond Lane					
Buses	81	2,835	35.00	27	945
Carpools	3,738	10,980	2.94	1,246	3,660
Total HOV	3,819	13,815	3.62	1,273	4,605
General Traffic Lanes	11,936	14,182	1.19	1,190	2,364
Shoulder	2,855	3,120	1.09	952	1,040
All Lanes	18,610	31,117	1.67	1,551	2,593

Note: (1) All diamond lane figures include buses & lane violators.

(2) Total peak period lane hours are 3 each for the HOV diamond and shoulder lanes (3 hours

Source: Virginia Department of Highways and Transportation, May, 1988.

level of service C or better. In spite of heavy congestion, the diamond lane usually has higher speeds and is more reliable than the general traffic lanes or the right hand shoulder, which is opened to general traffic during peak period. During the peak hour, the diamond lane with 25 percent of the highway's capacity, i.e one of four lanes, accounts for 53 percent of passenger volume in 22 percent of the vehicles.

Many fewer buses and bus riders use the I-95 diamond lanes than the Shirley HOV lanes. This is due principally to the fact that WMATA does not serve the area and the patterns of trip making by users of the facility. Only 81 buses (primarily private commuter buses) used the diamond lane during the AM peak period. Even so, as Table 7-3 indicates, nearly 3,000 AM peak period bus passengers used the I-95 diamond lane in May 1988. Bus passengers accounted for 21 percent of all peak period person trips, even though buses comprised only two percent of all peak period diamond lane vehicles.

The January 1989 reduction in the carpool criterion from 4+ to 3+ has apparently had only a minor impact on use of the I-95 diamond lane. Comparison of AM peak period use of the facility between December 14, 1988 and February 14, 1989 indicate that both vehicle and person use increased by 4 percent, a change that could be due entirely to seasonal variation. Vehicles (bus and carpool) increased from 3,767 to 3,926, and total passengers increased from 14,242 to 14,792. Average vehicle occupancy remained the same.

The I-66 HOV Parkway

The 10 mile I-66 extension is a four lane parkway, i.e, two lanes in each direction, running between the Capital Beltway (I-495) and the Roosevelt Bridge over the Potomac River into the District of Columbia. The I-66 Parkway includes a heavy-rail transit line (the Orange Line) in the median and three Metrorail stations (Vienna, West Fall Church and East Fall Church), approximately 8 miles of paved and lighted hiking and biking paths within the right-of-way, and specially designed noise and retaining walls. In December 1982, the I-66 HOV extension was opened as the nation's <u>first</u>, and still only peak period, peak direction <u>bus and carpool highway</u>.

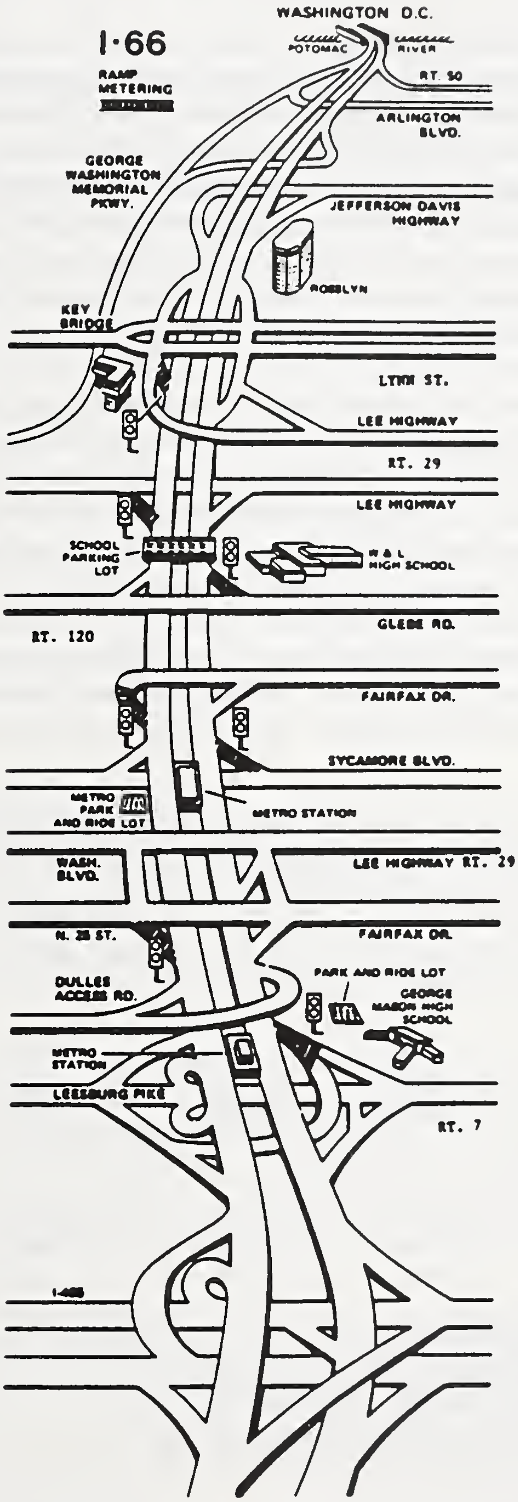
At its inception, only buses and 4+ carpools were allowed to use the road inbound (toward the District) during the 6:30 - 9:00 AM period and the same restrictions applied outbound from 3:30 - 6:30 PM. However, in January 1984, Congress mandated a change in the carpool definition to 3+ and reduced the duration of the two restricted periods by 30 minutes each, to 7-9 AM and 4-6 PM.*

As Figure 7-5 shows, there are 8 eastbound and 7 westbound entrances to the I-66 HOV Parkway. Three of the eastbound and 4 of the westbound access ramps are metered. The metered ramps are part of a computer controlled traffic management system implemented in June 1985. The system includes ramp metering, motorist advisory signing, and incident detection and management.

* As with the Shirley Highway, these changes were first implemented as a one year demonstration and then made permanent.

Figure 7-5.

I-66 Highway Interchanges



Source: Arnold and Lantz, 1985, G-3.

The Metrorail Orange Line extension to Vienna (in the median of I-66) was completed in June 1986. There are two Metrorail stations along the 10 mile I-66 restricted section with more than 4,500 parking spaces, which facilitate transfers between I-66 buses and carpools to Metrorail (NVCOG, 1987, p.7).

As the data in Table 7-4 indicate, on a typical workday in 1988, nearly 4,000 vehicles used the I-66 HOV Parkway during the AM peak period in the peak direction. Since there are 5 lane hours of restricted operations during the AM peak period (2 lanes times 2.5 hours) an average of 789 vehicles used each lane each hour during the AM peak period. These levels are obviously well below the facility's capacity.* Peak direction users of I-66 are thus able to travel at, or above, the posted speed limits and obtain significant time savings relative to persons using other routes. Bus and carpool users of the I-66 HOV Parkway, save approximately 12 to 15 minutes as compared to the most direct alternative routes serving the district, i.e. Route 50 and the George Washington Parkway (Arnold and Lantz, 1985, p. ix.).

At the present time, the I-66 HOV Parkway, even though it operates at well below its vehicle carrying capacity during peak periods, carries more people during these restricted periods than it would if it functioned as an unrestricted general purpose highway. As Table 7-4 indicates, the I-66 HOV Parkway carries 5,800 persons in 1,640 vehicles during the AM peak hour (7-8 AM). This is significantly more persons than I-66 would have carried if it operated as an unrestricted highway with an average of 1.4 occupants per vehicle.

While traffic is free flowing during most of the restricted period, significant delays occur just after the restricted peak period, when vehicles with fewer than the required three 3 occupants flood the facility (JHK, 1985, p. 34). Large numbers of vehicles wait for the end of the re-

Table 7–4. I–66 HOV AM Eastbound Peak Hour and Peak Period Vehicle and Passenger Volumes, May 1988

Time & Mode	Vehicles	Persons	Average Occupancy	Per Lane Hour Vehicles	Per Lane Hour Persons
Peak Hour (7–8 AM)					
Buses	19	665	35.00	10	333
Carpools	1,619	5,130	3.17	810	2,565
All	1,638	5,795	3.54	819	2,898
Peak Period (6:30–9AM)					
Buses	49	1,715	35.00	10	343
Carpools	3,896	10,161	2.61	779	2,032
All	3,945	11,876	3.01	789	2,375

Note: (1) All figures include buses and lane violators.
(2) Total number of parkway peak period lane hours is 5 (2.5 hours times 2 lanes). The counts are taken west of Key Bridge.
Source: Virginia Department of Highways and Transportation, May, 1988.

* The level of service C vehicle capacity for the I-66 Parkway is approximately 1,200 to 1,500 vehicles per lane per hour.

stricted period at on-ramps and on the shoulders of I-66, at the approaches to the restricted segment. This creates hazardous conditions at several entry points to the facility. As with the Shirley HOV lanes, motorists have adjusted their departure times with the result that the AM and PM peak hours occur immediately following the restricted period.

Unrestricted peak period, non-peak direction vehicle volumes on I-66, i.e. westbound traffic during the AM peak period and eastbound traffic during the PM peak period, exceed those in the peak direction. These higher vehicle volumes reflect the lack of restrictions and the significant reverse commuting to jobs in Northern Virginia. While during the peak period, non-peak direction vehicle volumes are higher than peak direction vehicle volumes, person trip volumes are much higher in the peak direction than in the off-peak direction.

Enforcement of carpool restrictions is a problem on I-66, as indicated by the average carpool vehicle occupancy of 2.6 for the peak period (Table 7-4). Enforcement is particularly problematic immediately after the restricted periods begin and before they end. While restricted period violation rates during March 1988 were only eight percent; Jeffrey (1987) estimates they are 40 percent for the 15 minute intervals at the start and end of each restricted period.

The I-66 HOV Parkway has the most limited bus service and fewest bus riders of the corridor's three HOV facilities. As the data in Table 7-4 indicate, slightly more than 1,700 persons used I-66 for inbound bus trips by bus during the AM peak period in May 1988. Even so, while buses comprise only one percent of peak-period, peak-direction vehicles, they carried more than 14 percent of all person trips. WMATA buses accounted for only seven of the 49 bus trips using I-66 during the AM peak period.

Development of the I-66 HOV Parkway

I-66 is a 75-mile highway extending from I-81 in Virginia's Shenandoah Valley to the District of Columbia. Before December 1982, there was no direct roadway between the Capital Beltway (I-495)/I-66 Interchange and the District of Columbia; commuters to the District of Columbia used routes 29 and 50 and the George Washington Parkway (Figure 7-1).

Planning for the I-66 extension, referred to here as the I-66 HOV Parkway, began in 1959 with a proposal for an 8-lane freeway. As planning and design of the proposed I-66 extension proceeded, however, vigorous opposition to the project arose, fueled by concern about its probable environmental impact and a more general opposition to large-scale freeway projects. After much controversy, several court decisions, and numerous design changes, the Virginia Department of Highways and Transportation submitted plans for a 4-lane, multi-modal facility to the FHWA for approval in 1976.

In January 1977, William Coleman, Secretary of the United States DOT, approved construction of the I-66 extension subject to certain conditions. Key conditions included:

1. The reservation of right-of-way in the median for the construction of a Metrorail line;

2. Restrictions of peak direction and peak period use of the facility to buses and to vehicles carrying four or more persons, emergency vehicles, and vehicles bound to or from Dulles Airport; and

3. The inclusion of design features that would minimize adverse environmental impacts.

Virginia's governor agreed to these conditions, and construction of the I-66 extension began in Fall 1977 (Arnold and Lantz, 1985, p.5).

When the I-66 extension first opened, 970 vehicles, consisting of 900 carpools and 70 buses, used the two lane facility in the peak direction during the peak hour (Christiansen, 1985, p.38). Peak period volumes averaged 2,080 vehicles, or approximately 25 percent of the effective vehicle capacity of the facility at level of service C. As a result, cars and buses using the facility during the designated peak periods moved at, or even above, the posted speed limits and experienced little or no delay. In 1983, average speeds for the restricted segment of the I-66 HOV Parkway were 48 mph during the AM peak period, as contrasted with speeds of 29 mph west of the Capital Beltway (in the unrestricted section of the highway).

Even though they used only a fraction of the vehicular capacity of the I-66 HOV Parkway, over 6,000 persons (3,900 carpoolers and 2,240 bus riders), used the facility when it first opened in 1982. If the I-66 HOV Parkway had been operated as a regular highway with an average auto occupancy of 1.4 persons per car, its person trip capacity would have been 5,600 at level of service C. Thus, even though motorists felt the I-66 HOV Parkway was underutilized, it, in fact, carried 10 percent more persons than if there had been no bus use and if auto occupancy rates were at typical levels.

As mentioned previously, the I-66 HOV Parkway carpool definition was reduced from 4+ to 3+ in January 1984. The decision to lower the threshold for carpools reflected a strongly expressed public perception that the I-66 HOV Parkway was seriously underutilized during the peak periods. As expected, the change in the carpool criterion from 4+ to 3+ led to a large increase in peak period vehicle and person trips. According to JHK (1985), the number of inbound person trips using I-66 during the AM peak period (6 to 9 AM) increased 37 percent from 29,313 in 1983 to over 40,000 in 1984. Inbound peak hour person trips increased by nearly a third, vehicle trips more than doubled, and the carpool share of total peak direction, peak hour trips increased from 63 percent to 71 percent (Christiansen, 1985, p. 44).

Vehicle and person volumes also increased during the three one-half hour unrestricted shoulder periods (6:30-7 AM, 3:30-4 PM and 6-6:30 PM). These increases in vehicle and person volumes, however, were obtained at the expense of much lower speeds and degraded service levels. During these periods, I-66 became extremely congested both immediately before and immediately after the periods the carpooling restrictions were in effect. Worse yet, congestion during the 6:30-7 AM and 3:30-4 PM shoulders adversely affected conditions on I-66 for 15 to 30 minutes of the restricted peak period.

As a result of the extreme congestion that occurred during the shoulders of the peak periods, the original restricted hours were reintroduced after the demonstration (6:30-9 AM and 4-6:30 PM). These changes largely eliminated the spillover effects and enabled carpools to travel

during more desirable commuting hours. At that time, one year after the experiment was initiated, the 3+ carpool criteria was made permanent and it continues to this day. Transportation officials in the area, however, anticipate that increased use of the facility will make it necessary to reinstitute the 4+ carpool criteria in the not too distant future (JHK, 1985, p. ii).

The I-66 HOV Lanes and Corridor Travel

It is difficult to determine the net impacts of the I-66 HOV scheme on corridor travel. The difficulty arises primarily from two considerations:

- The problem of determining the effect of the newly completed I-66 Parkway on other corridor facilities, including their impact on the Shirley HOV lanes;

- The difficulty of distinguishing the impacts of the I-66 extension from impacts of the "HOV lanes" because both were implemented at the same time.

Completion of the I-66 Parkway from inside the Beltway to the District of Columbia added significantly to the corridor's vehicle and person carrying capacity. Before the I-66 extension was opened, the corridor was served by six inbound lanes of limited access highway: Route 50 (two lanes), Route 29 (two lanes), and the George Washington Parkway (two lanes). Implementation of the HOV lanes thus increased inbound peak period vehicular capacity by roughly one-third and person carrying capacity by even more.

Available vehicle and person trip data suggest that the I-66 HOV lanes did increase carpooling in spite of a large overall increase in vehicular capacity in the corridor and lower travel times for low occupancy vehicles. With the opening of the I-66 extension, peak period vehicle volumes in the corridor (the I-66 Parkway, Route 50 and the George Washington Parkway) declined by approximately 5 percent. At the same time, total person trips increased suggesting that the I-66 HOV scheme did induce more carpooling (Southworth and Westbrook, 1985).

The net impact of the scheme, however, cannot be measured by changes in vehicle travel on the I-66 and the most direct alternative routes, Route 50 and the George Washington Parkway, alone, since many I-66 carpoolers were former users of the Shirley Highway HOV lanes. Survey data indicate that 93 percent of carpoolers using the I-66 HOV lanes, were members of carpools prior to the opening of the I-66 extension and over 41 percent of them had previously used the Shirley Highway HOV lanes (JHK, 1985). These data also indicate that 79 percent of I-66 bus users had previously commuted by bus. These numbers indicate that the net benefits of the I-66 HOV on corridor travel were significantly smaller than the gross ridership figures for the facility might suggest.

Cost-Effectiveness of Washington's HOV Facilities

Since the three HOV facilities are located in freeway right of ways and were built in conjunction with the building or reconstruction of larger facilities, it is very difficult to develop accurate capital cost estimates for them. Nonetheless, Table 7-5 contains estimates developed by Jeffrey (1987) and Christiansen (1985) for all three facilities.

Table 7–5. Characteristics, Costs, and Utilization of Northern Virginia HOV Facilities and Metrorail: Entire System and Northern Virginia (costs are in 1989 dollars)

Facility	Date Opened	Total Lanes	Length (Miles)	Capital Costs (Millions)	Passenger Volume Inbound AM Peak Period			Capital Cost Per AM Trip	
					Transit	Carpools	Total	Transit	Total
Shirley HOV Lane	1969	2	12.0	$125.2	14,070	18,838	32,908	$8,901	$3,806
I–66 HOV Parkway	1982	4	9.6	$176.6	1,715	10,161	11,876	$102,973	$14,870
I–95 Diamond Lane	1985	2	6.0	$5.7	2,835	10,980	13,815	$2,018	$414
Shirley plus I–66			21.6	$301.8	15,785	28,999	44,784	$19,122	$6,740
All HOV			27.6	$307.6	18,620	39,979	58,599	$16,517	$5,248
Metrorail									
Entire System			60.5	$8,122.3	93,275	NA	93,275	$87,079	$87,079
Northern Virginia					27,000	NA	27,000	NA	NA

Source: Jeffrey, 1987; Christiansen, 1985, p.48; & data from VDOT.

As we discussed previously, the Shirley Highway HOV lanes were built in conjunction with a highway project to upgrade and widen an existing grade-separated urban arterial. Christiansen (1985) estimates the capital cost in 1989 dollars of the Shirley Highway express lanes at $125.2 million or $5.2 million per lane mile.*

Cost estimation and allocation for the I-66 HOV Parkway is even more difficult since carpools and buses use the entire facility in the peak direction during the peak period. The critical issue is the allocation of total highway construction costs between peak direction and off-peak direction users and between peak and off-peak users. The capital costs of the entire 9.6 mile I-66 extension, however, have been estimated at approximately $176.6 million (1989 dollars) or approximately $4.6 million per lane mile. These costs are an approximation of the total $349 million cost minus the many costly "environmental add-ons" described previously, that were part of the compromise between anti-freeway activists and freeway planners. This is in order to allow a better comparison with the other facilities mentioned in this report.

As expected, the per lane mile cost of implementing the I-95 diamond lanes was significantly less than the costs of the Shirley Express lanes and I-66. The cost of the diamond lanes has been estimated at $5.7 million in 1989 dollars or $.5 million per lane mile (Jeffrey, 1987, p.79). These costs were incurred in marking the roadway and in building an emergency shoulder on the right hand side of the roadway where no shoulder had previously existed.

The three Washington D.C. highway HOV facilities cost only a fraction of Metrorail capital costs. The combined capital costs in 1989 dollars of the three HOV facilities have been estimated at $308 million, while the 1989 dollar capital cost of the Metrorail has been estimated at nearly $8.1 billion (Pickrell, 1989, Table 4). The last two columns in Table 7-7 compute capital

* All figures, unless otherwise noted are in constant 1989 dollars. Construction costs are converted into 1989 dollars using the ENR Construction Cost Index, all other costs are indexed using the GNP Implicit Price Deflator.

costs per AM peak period inbound Transit, HOV, and Metrorail trip. The capital cost per inbound Metrorail trip based on 1985 ridership was $87,079 in 1989 dollars. The combined capital cost per bus trip for the Shirley Highway and I-66 was $19,122; if carpools are added, this cost falls to $6,740 per trip (both amounts are in 1989 dollars). These costs are even less for the I-95 HOV lane. Capital costs per transit trip are only $2,018 and capital costs per total AM peak hour trip are a mere $414 (again, both in 1989 dollars). Taking the three HOV facilities as a group, their capital total costs per AM peak period trip (buses plus carpools) are $5,248; the same figure for METRO is $87,079 (all in 1989 dollars).

Future Plans for HOV Facilities

Virginia DOT plans to extend the two reversible Shirley Highway express lanes onto I-95 (Jeffrey, 1987, p.81). Virginia DOT is also considering restriping the two Shirley Highway HOV lanes to create three narrower HOV lanes when demand begins to exceed the level of service C criterion that it has established for the facility. Officials of Virginia DOT believe the existing 44 foot wide roadway could be restriped to provide either three 12 foot wide lanes with one 8 foot shoulder, or three 11 foot lanes with one 11 foot shoulder.

The long range plan for I-66 calls for 21 miles of reversible HOV lanes (west of the 10-mile extension) in the median similar to those on the Shirley Highway. The estimated costs in 1989 dollars of this improvement are $471 million (Jeffrey, 1987, p.81). In the shorter term, Virginia DOT plans an interim diamond lane solution on I-66, west of the Beltway, similar to that currently operating on I-95. The shoulders will be reconstructed to provide an additional lane in the median. Construction is expected to be completed by 1991, at a cost of $15 million (Jeffrey, 1987, p.81).

Conclusion

Since the opening of the Shirley express lanes over 20 years ago, the Washington D.C. metropolitan area has been particularly innovative with highway HOV facilities. Over time, the design and operation of the three most significant facilities, the Shirley Highway express lanes, the I-66 HOV Parkway and the I-95 diamond lanes, have been adjusted to changing traffic conditions, commuter requirements, and the introduction of Metrorail. In spite of the introduction of Metrorail, D.C.'s HOV facilities continue to be a critical part of the metropolitan area transportation network, particularly in the Northern Virginia corridor, and have in fact been integrated with Metrorail service. The Washington, D.C. experience, including future plans for expanding on present schemes, demonstrates the flexibility and enduring value of highway HOV facilities.

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Chapter 8. An L.A. Success: the El Monte Busway

Introduction

Los Angeles, the nation's second largest metropolitan area, has experienced rapid growth since the end of World War II. Between 1970 and 1985 its population increased by 24 percent to over 12 million. Furthermore, in spite of its low density and dispersed development pattern, Los Angeles' central business district (CBD) is the nation's sixth largest. According to census journey-to-work statistics, which are a lower bound estimate of CBD employment levels, at least 122,000 persons worked in the Los Angeles CBD in 1980. Only the New York, Chicago, Philadelphia and Washington, D.C. CBDs had more employment.

The Southern California region, including both Los Angeles and Orange County, has the further distinction of having the largest number of automobiles of any metropolitan area, and virtually no rail transit, although after many years of debate the region has begun an ambitious program of light and heavy rail construction. The region is linked together by an extensive and increasingly congested freeway system. In response to the nature of the region's development pattern and road network, the Southern California Rapid Transit District (SCRTD) in the 1950's initiated extensive express bus, "Freeway Flier", operations on the region's freeways, making Los Angeles Basin one of the first regions in the country to experiment with bus rapid transit and various bus carpool priority schemes.* The El Monte Busway was one of the earliest and most successful of the bus/carpool priority schemes.

The El Monte Busway

The El Monte Busway (Los Angeles I-10), which opened in 1973 as a bus-only facility, currently carries nearly 15,000 persons during the afternoon peak hour. Otherwise known as the San Bernardino Freeway Express Busway, the El Monte Busway, is one of the two earliest exclusive busways in North America. Like the Shirley Highway, which was opened to 3+ carpools in 1982, the El Monte Busway was converted to a bus/carpool facility in 1976.

The El Monte Busway is a joint project between the Southern California Rapid Transit District (SCRTD), the Southern Pacific Transportation Company, the California Department of Transportation (Caltrans) and the federal government. As such, it stands as a notable example of inter-governmental coordination and cooperation, as well as an extremely successful approach to increasing the capacity of one of Los Angeles' most congested highways.

* Southern California Rapid Transit District's extensive and highly successful freeway express bus operations were the inspiration for the name, Freeway Flier, used by Meyer, Kain and Wohl (1965) to describe the high-performance bus alternative evaluated in their comparative cost analyses. The "Freeway Flier" was described by Meyer, Kain and Wohl as a high-performance express bus system operating on a shared, uncongested, high-performance, limited access radial expressway. This description obviously closely approximates express bus operations on the El Monte Busway and other high performance bus-HOV facilities.

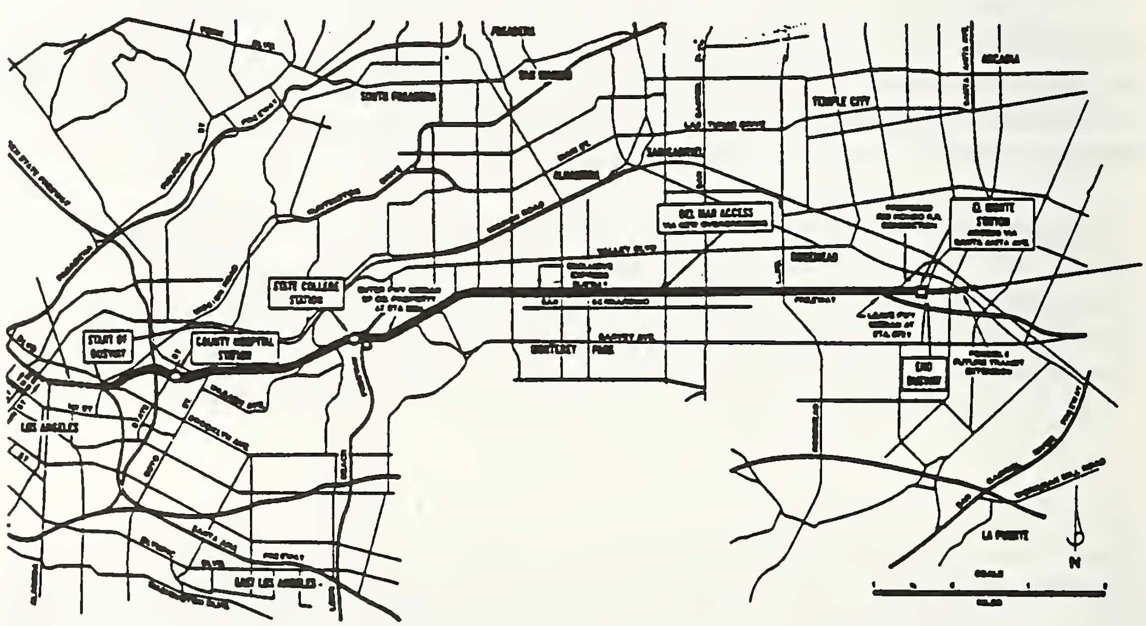
Description

In its current configuration, the busway is a two-way, two-lane (one in each direction), exclusive HOV facility constructed in the San Bernardino Freeway right-of-way. As can be seen from Figure 8-1, it extends west from the El Monte Bus Station to the Los Angeles CBD, a distance of a little more than 11 miles. The busway operates 24 hours a day, with buses, vanpools and 3+ carpools allowed to use the facility.

The busway consists of two distinct sections. The seven mile long eastern (outermost) segment is located in the median strip of the freeway, as shown in Figure 8-2a. There is one 17-foot lane in each direction separated from the main lanes by 10-foot paved shoulders with plastic stanchions. This section extends from Santa Anita Avenue to the Long Beach Freeway (Route 7).

Just before the San Bernardino-Long Beach Freeway interchange, the busway crosses the freeway main lanes on an overhead ramp to the north side of the freeway, where the remaining four miles run parallel and adjacent to the north side of the freeway. As shown in Figure 8-2b, this section consists of two 25 foot wide lanes that are separated from the freeway by a concrete barrier. West of College Station, the westbound busway lane crosses over the eastbound lane of the freeway. Both busway lanes run past the Hospital Station and terminate at Mission Road. For the remaining 1.3 miles into the CBD, high occupancy vehicles (HOVs) share the regular general purpose freeway lanes with other traffic.

Figure 8-1. The El Monte Busway



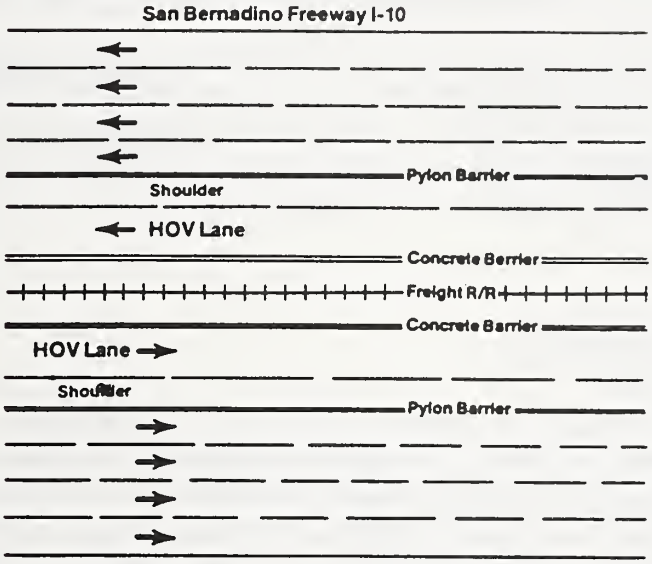
Source: Caltrans (1973).

Figure 8-2.

Typical View El Monte Transitway

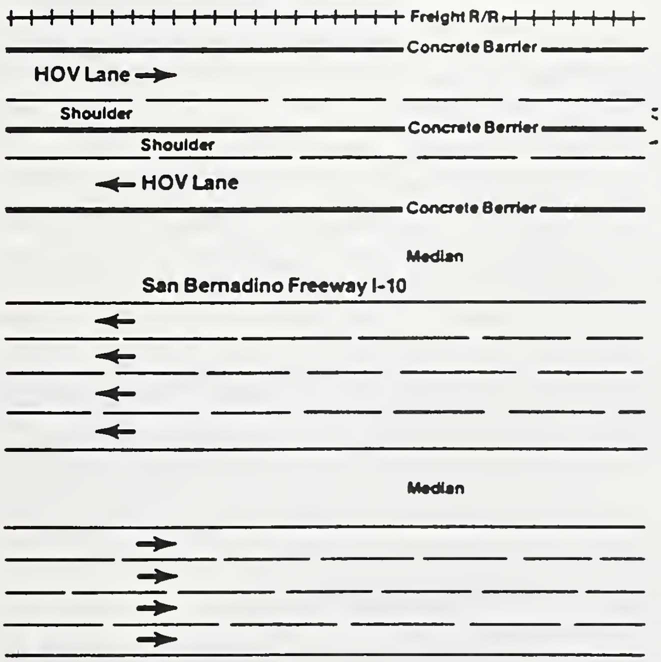
(8-2a.)

Long Beach Freeway to Gibson Overhead



(8-2b.)

From Mission Road to Long Beach Freeway



Source: METRO (Houston) Report, 1977.

Buses and carpools can enter the El Monte Busway at the Long Beach Freeway, Del Mar Avenue, the Santa Ana Freeway, and terminals at El Monte and Mission Road in downtown Los Angeles. Access ramps connect the busway to other freeways and to two intermediate stations, one at California State University at Los Angeles (College Station) and one serving the Los Angeles County General Hospital (Hospital Station). There are bicycle storage areas at College Station and the El Monte Station busway. The El Monte Station has 1,400 automobile parking places available for commuters; the lot has been fully used from the day the busway opened.

Data describing changes in ridership on the San Bernardino Freeway before and after the busway was opened demonstrate that the El Monte Busway has had a dramatic impact on bus and carpool use in the corridor. Furthermore, since the busway has existed for nearly two decades, it is possible to some extent to separate the effect of events, such as transit strikes and fare increases, on system ridership from other factors, such as overall growth in travel in the corridor.

History of the El Monte Busway

The time line in Table 8-1 records a number of milestones and major events affecting the El Monte Busway's early history, the period between its completion and August 1979. Between January and July 1973, only the eastern half of the busway was open and none of the stations were completed. Then in mid-July 1973, the El Monte Park and Ride Station opened and SCRTD quadrupled bus service in the corridor. From mid-1973 to early 1975, a number of additional system improvements were made that led to greater transit ridership. The western section of the busway was completed, bus routes entering the busway at the Del Mar ramps were added, the two intermediate stations were opened, and average bus fares were cut from $1.65 to $0.59 (in 1989 dollars).*

The numerous improvements described in the preceding paragraph were followed by a 10 week strike during the late summer and early fall 1974. SCRTD responded to the resulting increase in auto commuting and increased congestion by opening the busway to 3+ carpools during the last nine weeks of the strike. After the strike was settled, SCRTD returned the facility to exclusive bus use. Towards the middle of 1975, the El Monte Station parking facilities regularly began to be filled to capacity, and fares from El Monte to the Los Angeles CBD were doubled from $.54 to $1.08 (1989 dollars). Both developments had the expected effect of slowing the growth in transit ridership.

By early 1976, public demands to allow carpools to use the El Monte Busway had reached the point where they could no longer be ignored. At about the same time, analyses by SCRTD and by Bigelow-Crain Associates (1976), UMTA's consultants, hereafter referred to as Crain Associates, revealed that only about a third of the busway's capacity was being used during peak periods. The findings of these studies and disappointing outcomes from several bus system changes that were designed to increase ridership, were critical factors in persuading SCRTD to allow car and vanpools to use the busway.

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* Unless otherwise noted, all dollar amounts are in constant 1989 dollars. Construction cost dollar amounts are converted from current year to constant 1989 dollars using the ENR Construction Cost Index. All other costs are indexed using the GNP Implicit Price Deflator.

Table 8–1. Event Time Line – El Monte Busway, 1973–1979 (Dollar Amounts Are in Current Year Nominal Dollars)

Date	Event	Bus and Carpool Ridership 17 Hours	5.5 Peak Hours
1/29/73	Busway Opens (eastern segment only).	NA	1,150
7/15/73	El Monte Terminal opens, and bus service capacity doubles.	3,500	2,000
12/31/73	Del Mar Ramp opens.	6,050	4,100
4/1/74	Fares decreased to $0.25.	9,000	6,125
6/10/74	Final 3.5 miles of the busway opens.	10,200	7,800
8/74–10/74	SCRTD Strike.	NA	NA
11/5/74	Hospital Station opens.	10,600	8,000
2/18/75	College Station opens.	12,600	9,300
6/1/75	El Monte Parking filled, fares increased to $0.50.	NA	9,650
4/1/76	San Gabriel area–wide service introduced, Pasadena routes shifted to busway.	NA	10,470
7/1/76	Fares increased to $0.80.	NA	9,235
8/23–9/26/76	SCRTD Strike.	NA	NA
10/25/76	7 easternmost miles of busway opened to carpools.	NA	14,420
6/20/77	Entire busway opened to carpools.	NA	17,900
8/12/79	SCRTD Strike.	NA	22,760

On April 11, 1976, SCRTD expanded the coverage of its busway routes serving the San Gabriel Valley and re-routed two bus routes that served Pasadena so that they could use the busway. These changes had almost no effect on ridership. On the other hand, a 60 percent increase (from $1.01 to $1.62 in 1989 dollars) in SCRTD fares for busway services on July 1, 1976 did have an effect as ridership fell by 20 percent. Another bus strike, lasting from August 23 to September 27, was the straw that broke the camel's back; on October 25, 1976, SCRTD opened the seven easterly miles of the busway to 3+ carpools.

Carpool use of the El Monte Busway was limited to the easternmost segment until June 17, 1977 when the entire facility was opened to 3+ carpools. At the same time, SCRTD increased the average fare for its busway services from a flat $2.13 to $2.37 (both in 1989 dollars) or more. Real fares in 1989 dollars for busway services have fluctuated between $2.25 and $2.37 since 1977 and there have been very few route changes.

Ridership

The El Monte Busway's somewhat tumultuous history provides an unusual opportunity to assess the effects of various actions and events on ridership. In this regard it is useful to distinguish four phases of busway development:

> Stage I (January, 1973 to mid-June, 1974). Bus only use of the eastern seven miles of the busway.
>
> Stage II (June, 1974 to October 25, 1976). Bus only use of the entire 11 mile busway.
>
> Stage III (October 26, 1976 to June 19, 1977). Carpools (3+) and vanpools (3+) are allowed to use the eastern section of the busway.
>
> Stage IV (June 20, 1977 to the present). Entire busway is opened to 3+ carpools/vanpools.

Stage I: Transit use grows rapidly as buses using the first seven miles of busway save an average of 7.5 minutes per one-way trip vis-a-vis the general traffic lanes. As the data in Figure 8-3 indicate, transit ridership increased from 2,000 trips per day (17 hours, both directions) in July 1973 to 10,000 trips per day in March 1975. Figure 8-3 in addition to showing two hour peak, 5.5 hour peak, peak direction, and 17 hour, both directions transit ridership also identifies the major factors that affected ridership from the busway's opening until April 1975.

One issue that has not been addressed thus far is the busway's impact, if any, on the number of commuters using the freeway's general traffic lanes. At first glance, it would seem that inducing 8,000 additional riders to use transit would improve traffic conditions for the remaining motorists. This intuition is supported by the findings of a November 1974 survey which found that approximately 80 percent of riders on El Monte Busway routes previously made their trips by automobile (Crain Associates, 1976). Yet, average peak travel times on the general traffic lanes actually increased by one minute after the first section of the busway was completed.

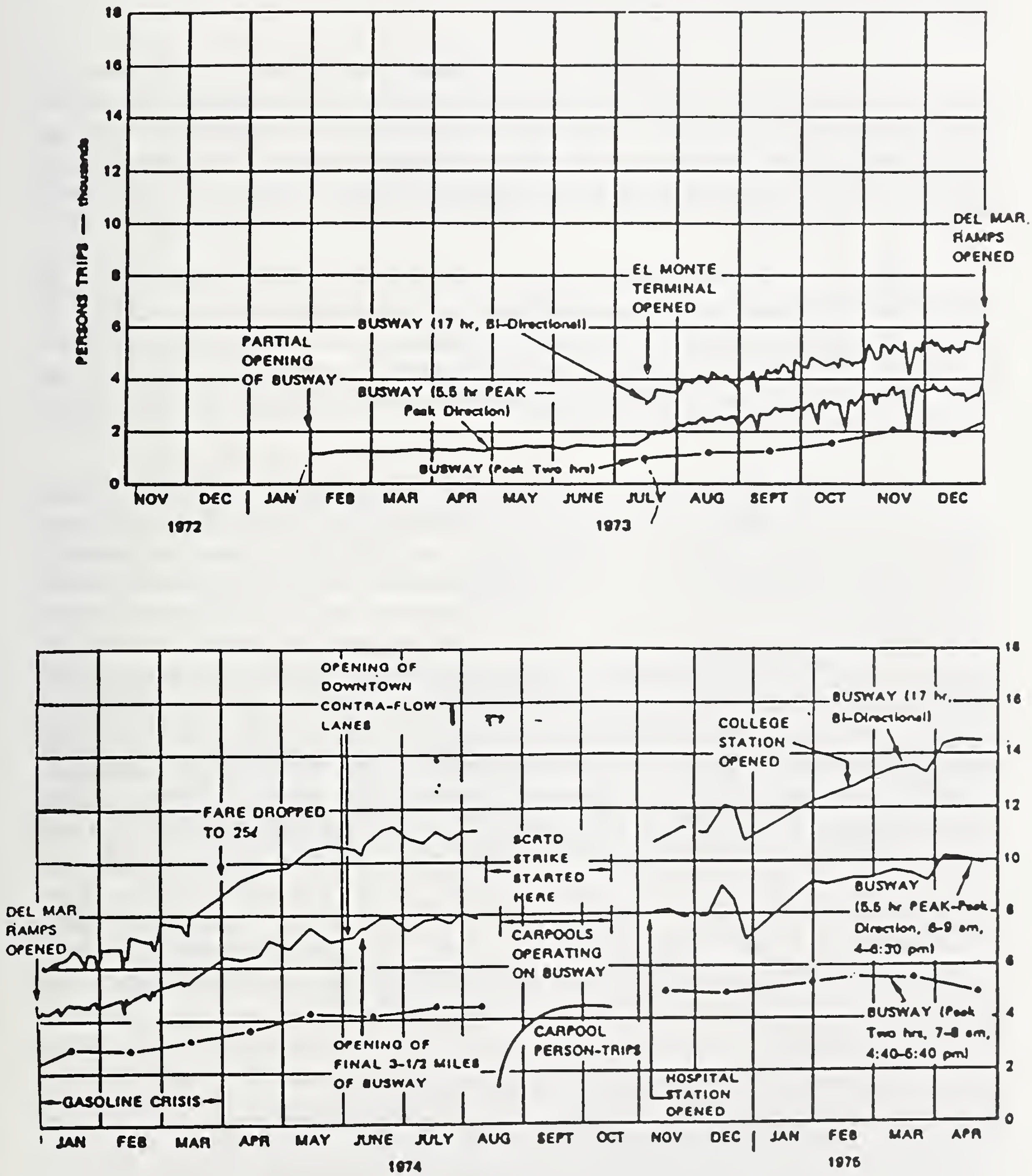
There are several possible explanations for the apparent increase in auto travel times in the general purpose freeway lanes during Stage I. General traffic growth may be part of the answer. In addition, the busway's initial success in diverting automobile drivers from the general purpose freeway lanes may have resulted in temporary time savings for vehicles in the general purpose freeway lanes, and these improvements may have drawn automobile commuters from parallel routes.* In addition, buses frequently had to cross congested general lanes to enter and leave the busway and these movements may have had an adverse effect on freeway speeds.

Transit ridership received a major boost in April 1974 when fares for the El Monte Busway services were cut by almost 65 percent to $0.59 (1989 dollars), see Figure 8-3. In less than two months, this nearly 65 percent decline in fares produced a 22 percent growth in ridership; bus ridership during the 5.5 hour peak period (6-9 AM and 4-6:30 PM) rose from 6,250 in

* Crain & Associates (1974, p.34) advance this hypothesis in their first report on the El Monte Busway.

Figure 8-3.

Person Trips on the El Monte Busway by Period
November 1972 - April 1975



April to 7,750 by mid-May, 1974.*

As Figure 8-3 makes clear, busway ridership continued to grow until a SCRTD strike interrupted service in August of 1974. It is possible that some, if not most, of this ridership increase may have been a delayed response to the fare decrease. At the same time, part of the ridership growth in late 1974 undoubtedly reflects the impact on ridership of opening an additional 3.5 miles of busway (in June 1974) and accompanying increases in transit service, as well as growing public awareness of the busway option.

At the end of Stage I, about 120 buses were using the busway during the AM peak hour; by comparison about 1,400 vehicles per lane were using each of the general purpose freeway lanes during the same time period. Even so, during the peak hour, the single busway lane served about 67 percent more persons than the average for each of the adjacent freeway lanes, i.e. approximately 3,000 one-way transit person trips per hour as against about 1,800 person trips per hour by car in each of the general purpose freeway lanes (Crain & Associates, 1976).

Stage II: The start of Stage II is defined by the opening of the entire busway to public transit in June, 1974. Bus ridership remained more or less constant from the start of Stage II until a second SCRTD strike about six weeks later on August 12, 1974. During the SCRTD strike, 3+ carpools, willing to obtain and display a special permit, were allowed to use the busway. Over 1,600 permits were issued, with the result that the busway was used by about 700 carpools and 2,300 persons per day (see Figure 8-3). **

After the 1974 strike, carpool use of the facility was discontinued and transit ridership quickly returned to pre-strike levels. Bus ridership grew steadily as two intermediate on-busway stations were opened, College and Hospital Stations. As Figure 8-3 indicates, bus ridership continued its steady growth until April 1975. Crain Associates (1975, p. 20) argue that the saturation of parking places at the El Monte Station brought the twenty-seven months of almost uninterrupted growth in transit ridership on the El Monte Busway to a halt. It is also true, however, that SCRTD raised bus fares by 100 percent in June of 1975, from $.54 to $1.08 (1989 dollars), a development which presumably accounts for at least part of the slower ridership growth. A further fare increase by SCRTD a year later, from $1.01 to $1.62 (1989 dollars), was followed by a ridership decline of approximately 20 percent. This ridership decline corresponds to a simple fare elasticity of -0.3, a value that is very close to the widely used Simpson-Curtin rule-of-thumb, i.e. -.33. A second month-long SCRTD strike (August 23-September 27, 1976), which occurred at the end of Stage II had a predictably adverse impact on transit ridership.

Stage III: On October 25, 1976, the eastern seven mile section of the El Monte Busway was opened to 3+ carpools during peak hours. As the data in Figure 8-4 indicate, AM peak period (6:30-8:30 AM), bus ridership in the previous month totaled 5,100. By November 1976,

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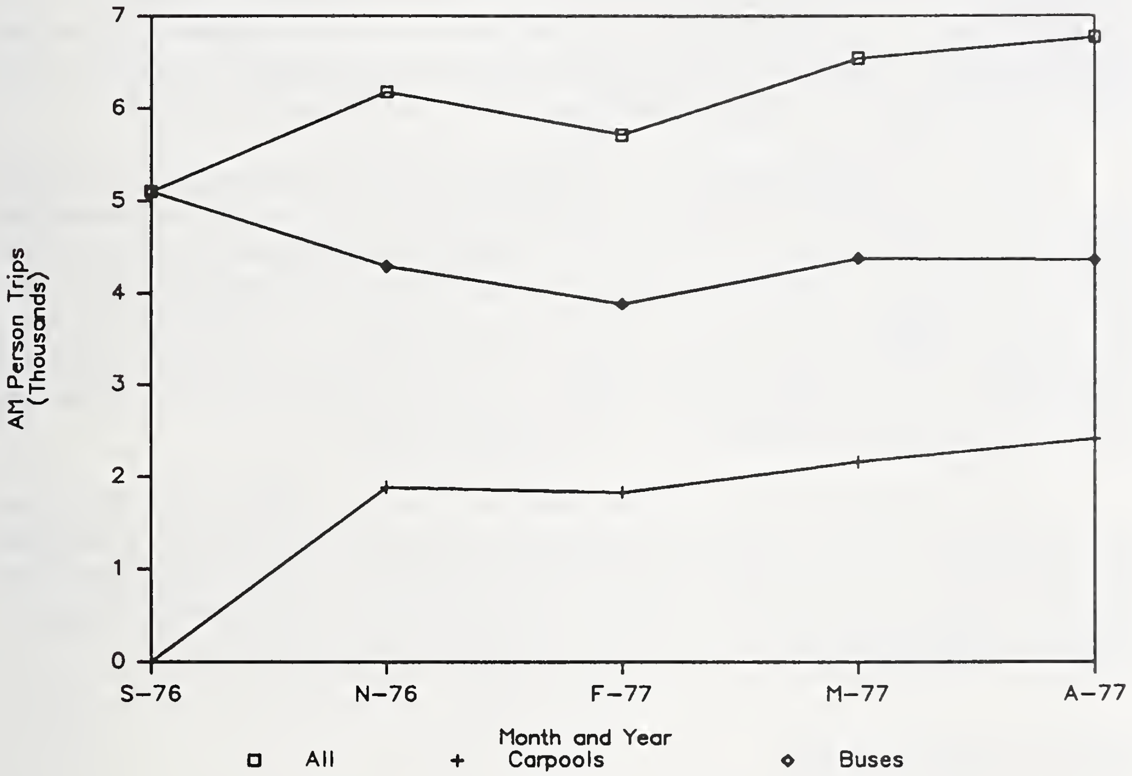
* The estimated peak period response to the fare reduction corresponds to a simple fare elasticity of approximately -0.20, a value that is somewhat smaller than the widely used Simpson-Curtin rule-of-thumb estimate of the fare elasticity of demand, which is -0.33. The smaller than usual elasticity may be due, in part, to the magnitude of the fare decrease and the relatively short period, i.e. six weeks, used in the calculating the ridership response.

** Once the strike was settled the busway was once again limited to buses only. For further information regarding this time period see California Department of Transportation-District 7 (1975).

Figure 8-4. AM Peak Period (6:30-8:30 AM) Person Trips by Bus and Carpool: El Monte Busway, September 1976 - August 1977



two months after the eastern section was opened to 3+ carpools, busway transit ridership had fallen to 4,300 per day, but total AM peak period person trips using the busway had risen to about 6,200. The 800 person trip decline in transit ridership was more than offset by an approximately 1,900 increase in AM peak period person trips in carpools.* By the time of the third count shown in Figure 8-4 (for February 1977), carpool use had leveled off and bus ridership had continued to decline. As a result, total AM peak period person trips were slightly less than they were at the time of the previous count. However, 600 more person trips (transit plus carpool) were still using the busway during the AM peak period than before the busway was opened to carpools.

There is some evidence that opening the busway to carpools caused at least a temporary decrease in traffic on the general purpose freeway lanes. According to Crain Associates (1978, p. 33), during the 1977 6-10 AM peak period, the number of single and double occu-

* It should be understood that the busway ridership data in Figures 8-5 and 8-6 are counts for single or in a few cases two consecutive days and at a single location. While Caltrans makes every effort to make their counts on representative days, individual observations may be influenced by special circumstances. Thus, not too much weight should be given to individual observations.

pancy cars increased approximately two percent, while the number of 3+ carpools using the general purpose freeway lanes fell nearly 30 percent.

The total number of vehicles (busway plus main traffic lanes) using the San Bernardino Freeway during the AM peak period (6:30-8:30 PM) grew from 15,700 before October 25, 1976, to 17,000 in June 1977. During the same period, the number of passengers increased from 23,400 to 26,000. The total number of 3+ carpools using the freeway increased by almost 100 percent (from 560 to 1100) during Stage III, even though average automobile occupancy for the entire freeway (including the busway) increased by only a small amount from 1.20 to 1.24.

Stage IV: At the same time (June 1977) that SCRTD and Caltrans agreed to open the entire length of the busway to 3+ carpools, SCRTD increased average fares for its El Monte services from $1.52 to $1.90 (1989 dollars). This fare increase, in combination with opening the remainder of the busway to carpools, caused bus ridership to fall by more than 30 percent. Average peak period ridership fell to 4,400 during the summer of 1977; the average number of carpoolers, however, rose to 3,400, for a total of about 7,800 AM peak period person trips. Bus and carpool ridership began to pick up again through the following fall and winter and, by September of 1979, AM peak period person trips on the busway reached 10,300.

During 1979, the number of carpools using the El Monte Busway increased by more than 56 percent over Stage III operations, while the average occupancy of carpools using the busway remained at approximately 3.3 persons. The number of 3+ carpools using all lanes of the freeway during the morning (6-10 AM) increased sharply to 1,870 vehicles, carrying approximately 5,600 passengers.

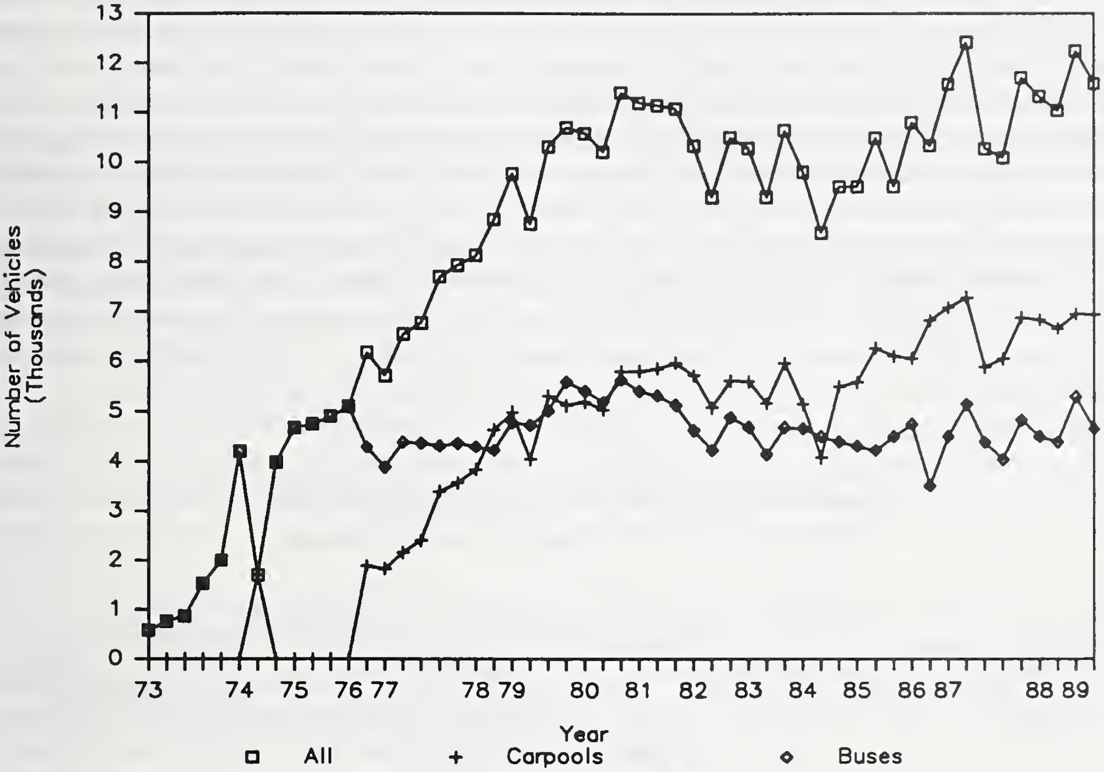
Overall Changes In Ridership

The preceding discussion emphasizes the changes in busway usage that occurred within each of the four stages of busway development. As a consequence, it tends to emphasize the effects of policy changes, fare changes, transit service level changes, and strikes. While this microscopic examination of busway ridership is useful, it also tends to obscure broader trends. An alternative, longer-run, perspective is provided by Figure 8-5 which shows total AM peak period (6:30-8:30 AM) person trips, transit trips, and person trips by carpool from the time the busway first operated until May 1989. Careful inspection of Figure 8-5 reveals that the number of data points varies from one year to the next; we are uncertain whether this means that Caltrans made a different number of busway counts from one year to the next or whether the data from some counts were lost. In either case, it would be a mistake to pay too much attention to individual data points.* On the other hand, the broad trends are unmistakable.

As is evident in Figure 8-5, total AM peak period (6:30-8:30 AM) person trips on the El Monte Busway grew rapidly at first, from 575 trips in February 1973 when the easternmost seven miles of busway opened to 4,200 trips in May 1974, just prior to the time (mid-June 1974) when the entire 11 miles of busway began operations as an exclusive busway, i.e. the start of Stage II. Thereafter, bus ridership continued to grow steadily until it reached 5,200 AM peak period trips

* We have also added some extra points for years in which the small number of points cause the years on the X-axis to become unreadable. In the case of these dummy observations, we interpolate between the values on either side.

**Figure 8-5. Number of AM Peak Period (6:30-8:30 AM)
Person Trips Using the Busway by Mode,
Various Dates 1973-1989**

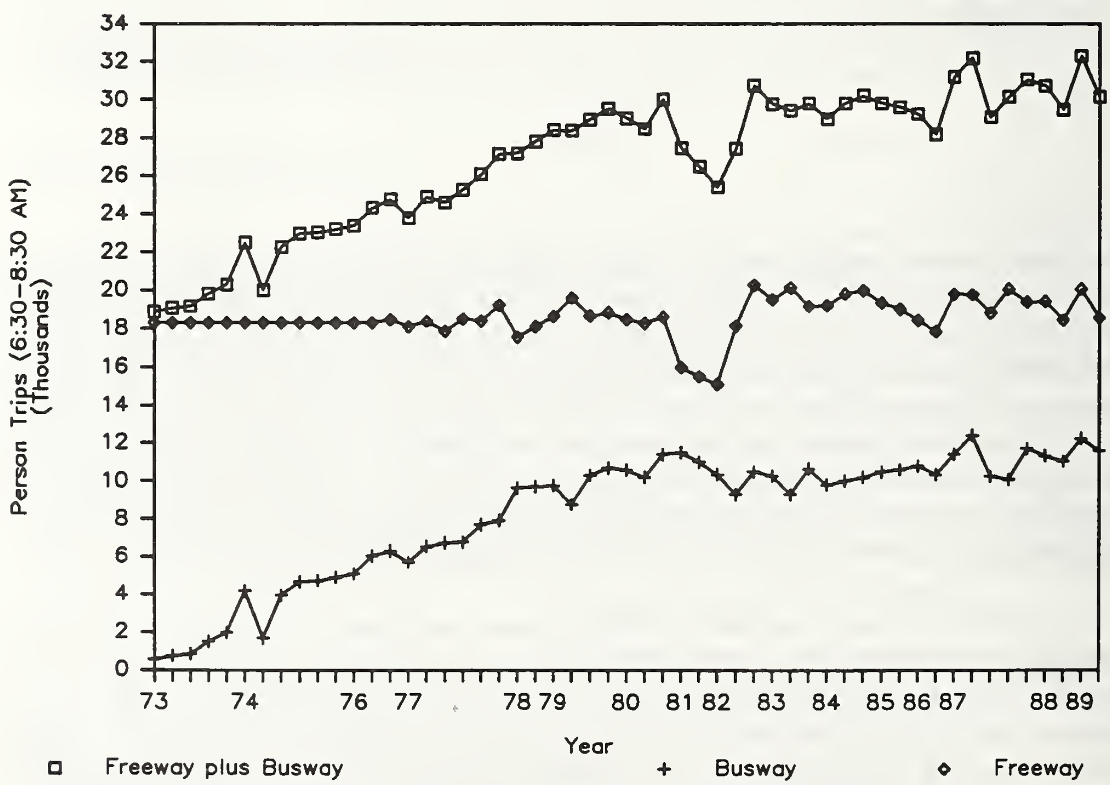


in the month before carpools began using the eastern section of the busway, i.e the start of Stage III (October 26, 1976). After the eastern section of the busway was opened to carpools on a regular basis, as contrasted with its intermittent use by carpools during SCRTD strikes, bus ridership declined sharply; it then recovered somewhat before it once again started to slowly trend downward. By the end of Stage III (June 19, 1977), AM peak period bus use at 4,300 trips was about 700 trips below the level that had been reached at the end of Phase II (October 25, 1976). During Phase IV, AM peak period bus trips first recovered a bit and then declined again, before they once again recovered. The most recent counts indicate that there were 5,300 AM peak period (6:30-8:30 AM) person trips by bus in February 1989 and 4,600 in May 1989.

In contrast to bus trips, which exhibit little trend during the 13 year period since the El Monte Busway was opened to carpools, total AM peak period busway ridership (buses plus carpools) continued to grow rapidly from October 1976, when the first segment of busway was opened to carpools to November 1980, until total AM peak period use of the busway reached 11,400 person trips. From that point, total AM peak period use of the busway fluctuated in the range 8,600-11,400. The most recent counts 12,200 (February 16, 1989) and 11,600 (May 25, 1989) are both higher than the November 1980 ridership figure.

The growth of ridership on the El Monte Busway has permitted the number of AM peak period person trips on the freeway as a whole to grow as well. Figure 8-6 shows the number of AM peak period person trips using the general purpose freeway lanes, the busway, and the entire freeway (freeway main lanes plus busway), from the time the busway first opened (January 1973) through May 1989. We were unable to obtain person count data for the general purpose lanes for the period before November 1976. As a result, we simply assume that these lanes were operating at or near capacity, and that AM peak period person use of the general purpose freeway lanes during this period was a constant 18,000 person trips. This assumption may slightly understate the growth in AM peak period person trips in the general purpose freeway lanes during 1973-76, but the effect is likely to be small. Starting with the end points in Figure 8-6, total AM peak period (6:30 - 8:30 AM) person trips on the entire freeway were about 19,000 in January 1973 as compared to about 30,000 in May 1989. As inspection of Figure 8-6 reveals, the growth in total freeway per person travel was almost entirely due to the growth in busway usage. Considering the end points once again, the number of person trips in the main lanes were almost identical, 18,300 in 1973 and 18,500 in May 1989. AM peak period busway person trips over the same period, however, increased from about 500 in 1973 to 6,000 in 1976, and finally to 11,600 in 1989.

Figure 8-6. Total AM Peak Period (6:30-8:30 AM) Person Trips for the Busway and the Freeway



Source: Caltrans, various counts.

Time Savings

Buses and 3+ carpools using the El Monte Busway during peak periods currently save about 10 minutes per trip relative to vehicles using the freeway main lanes. It should be clearly understood, however, that 10 minutes is the average for the entire peak period; buses and 3+ carpools using the busway during the most heavily congested parts of the AM peak period realize time savings of up to 17 minutes.

Like most other urban freeways, the San Bernardino Freeway experiences two periods of serious congestion per day. Crain Associates, in their Final Report (1978), estimate that peak usage occurs at about 7:30 AM in the westbound (inbound) direction and about 4:45 PM in the eastbound (outbound) direction. The AM peak is shorter, is more concentrated, and has more serious congestion than the PM peak period. Vehicles using the HOV lanes, with the entire length of the facility open to carpools (Stage IV), average 52 mph during peak periods, while those using the general freeway lanes average about 26 mph.

Busway travel times are extremely predictable, while travel times, for low occupancy vehicles (LOVs) using the general freeway are highly variable, particularly on days when accidents occur. Depending on commuter sensitivity to on-time arrival, average commute time savings from lower variability in travel time might be as little as a minute or as much as 10 minutes (Crain Associates, 1975).

Opening the busway to carpools had very little or no effect on bus speeds and travel times. From the time the facility opened to the present time, bus speeds between El Monte and downtown L.A. have averaged 49 mph and average trip times have been approximately 13.5 minutes, including stops. Busway volumes peak at about 1,000 vehicles an hour but these peak flow conditions last for only a brief period of time, around 20 minutes.*

Crain Associates (1978, p.51) found that the El Monte Busway could accommodate up to 1,200 vehicles per hour with no degradation of transit service. At vehicle volumes above 1,200 vehicles per hour, however, they found bus speeds and reliability would begin to decline, and, as the number of peak hour vehicles using the busway began to approach 1,800, busway speeds would be similar to the congested conditions existing on the general purpose freeway lanes during peak periods. The fact that more-or-less free-flowing conditions prevail on the busway indicates that the busway still has considerable available capacity.

While it is evident that the El Monte Busway provides substantial time savings for 3+ carpools, relative to autos with less than three passengers, it is less obvious that the trips of bus users take less time than if the same trips were made in a single occupancy vehicle. The additional time commuters require to reach the nearest park and ride or bus station (through walking, getting a ride, or taking a feeder bus) will frequently exceed the savings they obtain by choosing

* Oddly enough, average travel times on the busway appear to have declined somewhat since the facility was opened to car and vanpools. There are a number of possible explanations for this phenomena: car and vanpools may have higher average speeds than buses, so allowing them to use the busway might well account for the increase of average busway vehicle speeds; bus schedules might have been changed when car and vanpools were allowed to use the busway; and opening the entire length of the busway to car and vanpools might have eliminated some of the congestion that might have occurred when carpools had to leave the busway at the Long Beach Freeway Interchange. Discovering the exact reasons for the change in busway speeds would require more extensive research than was possible as part of this report, and is presumably of no great significance in any case.

the bus mode rather than the LOV mode. Travel time savings for bus users depend on 1) the time at which they start their trip, and 2) their method of access to the most convenient bus station.

Capital and Operational Costs

Setting aside the problem of the opportunity cost of the right-of-way, calculating the incremental capital cost of the El Monte Busway is quite straightforward. Capital costs in 1989 dollars for the entire 11 miles plus of busway were $107 million (approximately $9.6 million a mile), including the cost of relocating the Southern Pacific Railroad line. Of the $107 million project costs, $65 million was used to construct the busway, right-of-way costs were $19 million, and an additional $17 million was spent for supporting equipment and facilities, including the acquisition of new buses and construction of a bus maintenance facilities.

Federal grants paid for $88 million of project costs; the State of California provided $8 million; the local governments, City and County of Los Angeles and the cities of El Monte and San Gabriel, supplied $380,000; and SCRTD and Southern Pacific Transportation Companies contributed a combined total of $10.3 million, which included $1.3 million for project evaluation (all in 1989 dollars).

Operating costs are more difficult to determine. The best available estimates of busway operating costs, prepared by Crain Associates (1975, p. 32), are based on 1974 SCRTD operating cost data. This analysis concludes that the average cost of operating a SCRTD bus on the El Monte Busway was $2.41 a mile, in 1989 dollars. Crain Associates analysts also prepared operating cost estimates for busway stations which they added to bus operating costs. After adjusting the data for users who ride the busway lines off the busway, i.e. commuters who board and get off the buses east of Del Mar, or within the downtown area, Crain Associates analysts estimated that the operating costs (including station cost) per passenger averaged $2.36 for the entire day and $1.89 during the peak periods, again in 1989 dollars.*

Only a small part of the operating costs of El Monte express bus services were recovered from the fare box. Single trip fares in 1989 dollars were $.59 per trip, but substantial discounts were given for passes and, as a result, revenues per passenger averaged only about $.24 per trip. Subsidies in late 1974, therefore were required to cover nearly 90 percent of per trip operating costs.

Safety Issues and Violations

Analyses by Crain Associates (1978) indicate that the busway had no effect upon corridor accident rates and little or no impact on accident rates in the San Bernardino Freeway general purpose traffic lanes. Two possible exceptions to this finding, are short sections of the eastbound freeway lanes which experienced a noticeable increase in accidents after the busway was opened to carpools. In the Herbert Avenue/Long Beach Drive section, the number of acci-

* The somewhat surprising finding that peak period trips are less costly to provide than off-peak trips is due to a policy decision to provide significant amounts of off-peak service, even though the demand for these services is quite limited. It is unclear, moreover, how split shifts and other peak-related costs were treated in these calculations.

dents per year on the freeway increased from 19 in 1974-75, when only buses were allowed to use the busway, to 46 in 1976-77, when carpools were allowed to use the entire busway. Similarly, the number of accidents per year in the Rosemead Avenue/Baldwin Avenue segment of the busway increased from five to 18 in the same period. About 55 percent of these accidents occurred in either the busway lane, the merging lane, or the inside freeway lane, while the remaining 45 percent occurred in lanes at least one lane away from the busway.

Most busway related accidents are caused by vehicles making illegal turning movements onto or off the busway. Many such accidents occur during the PM period, in the eastbound direction between Herbert and Baldwin Avenues. Weaving violations, often by non-carpool vehicles, are the dominant cause of busway-related accidents. The physically separated western segment of the El Monte Busway is almost accident free.

Violation rates for vehicles with less than three persons are much lower for the El Monte Busway (10 percent) than for many other preferential lane projects. Since its initial period of carpool operation, the California Highway Patrol has not found it necessary to assign additional police to the El Monte Busway. Commuters seem to be quite reluctant to enter the physically separate busway with fewer then the required number of riders.

Accident rates per person-mile are very low for vehicles using the busway. The rate has hovered around 0.3 accidents per million person-miles for the last 10 years, which is less than one-third of the corresponding value for general purpose freeway lanes. The safety and enforcement experiences of the El Monte Busway is similar to that of the Shirley Highway express lanes, and markedly different from the increase in accident rates that occurred with the implementation of the aborted Santa Monica Diamond Lanes discussed in next chapter.

The key factor in explaining the different accident experience of the El Monte Busway and the diamond lanes is undoubtedly the extent of physical separation between the preferential lane and the adjoining freeway lanes. On the Shirley Highway, the separation is achieved by fixed concrete barriers. The same type of separation exists on a portion of the El Monte Busway, while other sections are separated by a wide shoulder marked with plastic stanchions. The Santa Monica Freeway diamond lane project, on the other hand, had no special separation from general purpose freeway lanes.

Overall Performance and Satisfaction

The transit market share of CBD commuters in the San Bernardino Freeway corridor grew to 24 percent by 1983 and has remained at this level ever since. The relevant market in these calculations are commuters to downtown Los Angeles from the eastern section of the corridor that is served by the busway. While the vast majority of transit riders in the corridor use busway services, approximately 10 percent use non-busway lines. The overall transit market share of commute trips to the CBD for the corridor is 28 percent.

The most recent SCRTD data (Spring, 1989) indicate that during the morning peak period (6:30 AM and 8:30 AM), approximately 2,300 vehicles use the busway. All but 130 or so are 3+ carpools. Approximately 100 of the buses are full, i.e. have close to 40 passengers, while the remaining 30 or so have significantly fewer passengers, i.e. 20 or fewer passengers per bus.

The busway currently carries almost 12,000 passengers during the AM peak period. More than 10,000 vehicles would be required to carry the same number of passengers in low occupancy vehicles, assuming the current average occupancy of 1.2 occupants per vehicle. Thus, in just two hours the busway diverts a minimum of 7,700 vehicle trips per day from the San Bernardino Freeway and parallel routes. The average number of vehicles on the busway during these two hours is only 1,150 vehicles per hour, a level that is significantly less than the 1,800 to 2,000 vehicles per hour in the general purpose freeway lanes during peak hours.

It is hardly surprising that the response to the El Monte Busway has been overwhelmingly positive. Early surveys of busway users indicated that the busway was a welcome addition for commuters on I-10. Use of the busway has kept growing, especially among carpoolers. As early as 1978, the net effects of increased busway usage were estimated to be the elimination of 4,300 one-way auto commute trips per day, savings of about 146,000 vehicle miles traveled per day, daily savings of 9,200 gallons of gasoline (including the use of diesel fuel by busway buses), and a reduction in air pollutants, relative to the environmental conditions which would have existed if there had been no busway (U.S. Department of Transportation and California Department of Transportation report, 1981). The increase in busway patronage of approximately 800 vehicles, in just the AM peak period, since 1978 only magnifies these numbers.

The success of the El Monte helped create a positive attitude toward preferential lanes and busways among both transportation planners and commuters in California. The variety and number of transportation innovations attempted by SCRTD and Caltrans contrasts sharply with the reluctance by plannings in many other parts of the nation to devise and propose such measures. California officials credit the El Monte Busway with creating an initial climate of commuter goodwill toward such efforts, and for demonstrating that well-designed and implemented transit projects could contribute towards accommodating the inexorable growth of travel in one of the most car-oriented urban areas in the nation.

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Chapter 9. Post El Monte HOV Development In Metropolitan Los Angeles

Introduction

This chapter describes and discusses the performance of several bus-HOV facilities and other bus priority schemes developed in Los Angeles after the El Monte Busway's successful implementation. These include the ill-fated Santa Monica Diamond Lane Demonstration Project, Caltrans's extensive ramp metering and bypass systems, the Route 91 and Route 55 commuter lanes, and the innovative transitway-commuter lane system now being planned for Orange County.

In 1976, three years after the El Monte Busway opened, Caltrans converted the east-bound and west-bound left-hand lanes of the Santa Monica Freeway to the exclusive use of buses and three or more occupant (3+) carpools during peak periods. This poorly planned and abortive effort, known as the Santa Monica Demonstration Diamond Lane Project, was stopped after 21 weeks by court order. The Santa Monica Diamond Lane experience "brought an effective halt to serious HOV facility planning" in Southern California for nearly a decade.

No new HOV lanes were implemented in Southern California until June 1985, when a commuter lane demonstration project was begun on the Artesia Freeway (Route 91). The Route 91 demonstration project was followed by a similar project on the Newport Freeway which began operations six months later. Both are now permanent HOV facilities. More recently, Orange County has begun serious planning for an extensive HOV system (Parsons Brinckerhoff, 1986). In the sections that follow, we review each of these experiences starting with the Santa Monica Diamond Lanes.

The Santa Monica Freeway Diamond Lanes*

The Santa Monica Freeway, which connects the City of Santa Monica and downtown Los Angeles, has long been one of the region's most heavily used and most seriously congested highways. Caltrans and SCRTD, not surprisingly, have made numerous efforts to improve conditions on the freeway and in the corridor. Immediately before the diamond lane project was implemented, for example, the Santa Monica Freeway was used as a pilot site to test the effectiveness of metered on-ramps and bus and carpool ramp bypasses. Subsequent innovations introduced on the freeway include a computerized surveillance system and centrally-controlled electronic traffic condition and commuter information displays. These projects improved traffic flow and travel speeds for vehicles using the freeway.

The diamond lane project was proposed as an innovative and inexpensive response to increasingly congested conditions on L.A. freeways. The notion of "taking away" an existing general traffic lane for use as bus/3+ carpool HOV-lane for a few hours a day during the peak commuting periods had a beguiling simplicity. It was referred to as the diamond lane project

* This section relies heavily on SYSTAN (1977).

because the peak period HOV lane was identified with diamonds painted every 20 feet on the roadway; as Figure 9-1 shows, there was no physical separation between the HOV lane and the general traffic lanes. Carpools and buses were free to enter and leave the diamond lane from the general purpose freeway lanes at their discretion and at any point; the only restriction was that vehicles using the diamond lane had to have at least three occupants.

On March 15, 1976, Caltrans, acting in conjunction with the California Highway Patrol (CHP) and local bus operators, reserved the median lanes in both directions of a 12-mile, eight-lane segment of the Santa Monica Freeway for the exclusive use of buses and 3+ carpools. At the time that the diamond lanes were opened, local bus operators introduced a number of new express bus services and opened three new park and ride lots in West Los Angeles.

Figure 9-1. The Santa Monica Diamond Lanes

Source: UMTA/TSC Project Evaluation Series, The Santa Monica Diamond Lanes Volume I: Summary, Final Report, 1977.

Although the diamond lanes required no major physical modifications or construction on the freeway, their implementation produced a strongly negative response from users of the general traffic lanes. The negative reaction was caused in part by the fact that the project got off to a poor start. The diamond lanes did not open as planned due to a combination of problems including operational difficulties, financial concerns, a local dispute over the implications of nationwide labor protective agreements, and the Southern California rainy season. When the diamond lanes finally opened, the first day of operations was a disaster, featuring bumper-to-bumper traffic, long queues at on-ramps, a malfunctioning ramp meter, many accidents, outraged drivers, and derisive media commentary.

Diamond lane performance improved over time and both bus and carpool ridership increased substantially; however, accidents remained a source of negative publicity. As a result, despite extensive efforts by Caltrans to persuade drivers that the project benefited them, media coverage and the climate of public opinion grew ever more hostile. The diamond lane project continued amid much controversy for 21 weeks until August 9, 1976, when Judge Matthew Byrne of the U.S. District Court in Los Angeles halted the project and ordered Caltrans to carry out additional environmental studies before continuing it. Although Judge Byrne's decision dealt primarily with the legal requirements for environmental impact analyses and reports and did not consider the merits of the diamond lanes, the project was never resurrected.

Project Description

The Santa Monica Diamond Lanes were located in the innermost (median) lanes of 12.6 miles of freeway between the Pacific Ocean in Santa Monica and the Los Angeles CBD (Figure 9-2). The lanes were reserved for buses and 3+ carpools in both directions from 6:30 - 9:30 AM (originally 6:00 - 10:00 AM) and 3:00 - 7:00 PM. Carpools and buses were allowed to enter and leave the diamond lane at any point over its entire length. Carpool eligibility restrictions (number of occupants), however, were strictly enforced, especially during the first few weeks of the project.

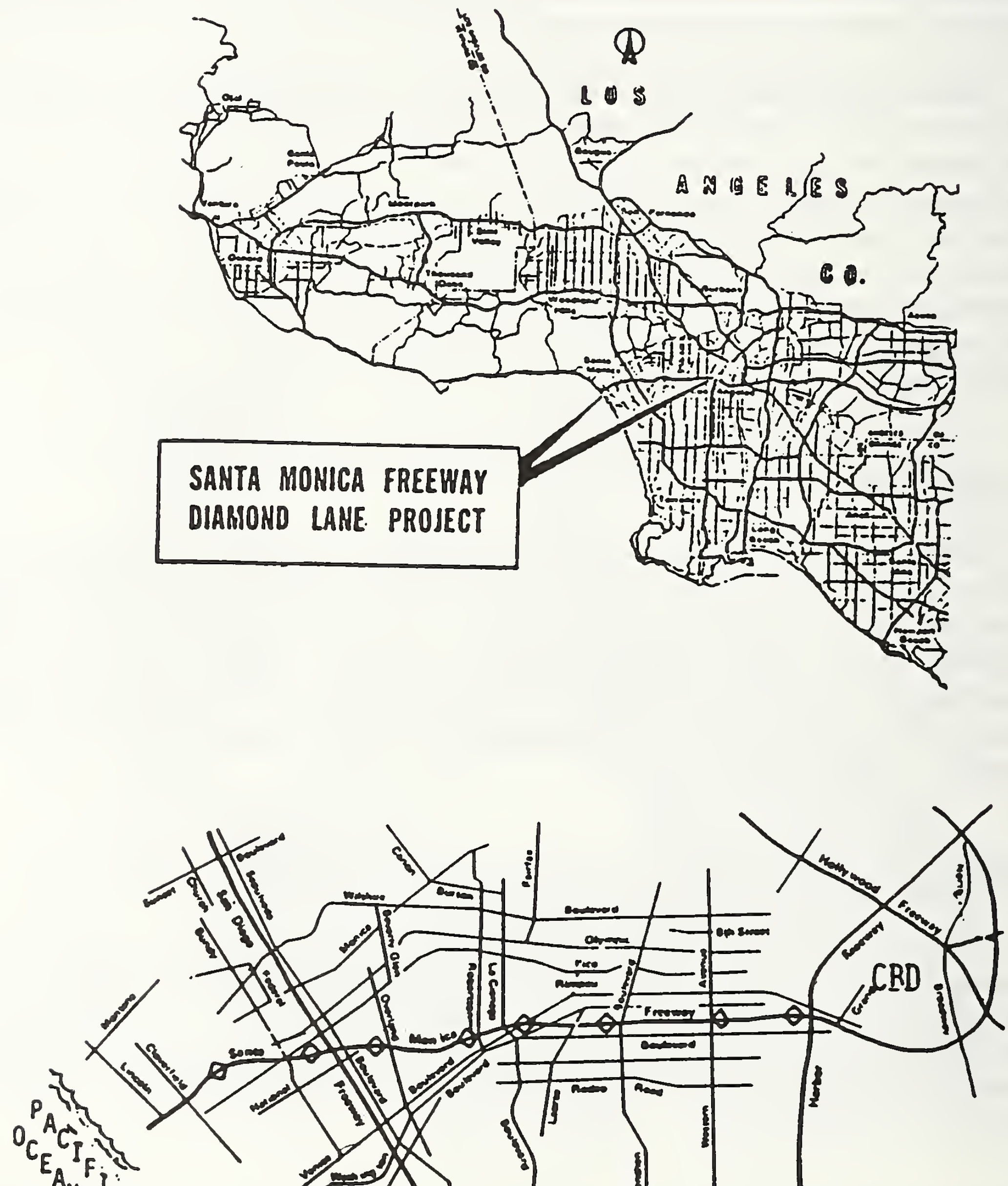
Traffic Speeds and Travel Times

Implementation of the diamond lanes had a marked impact on vehicle speeds on the Santa Monica Freeway. Travel in the diamond lanes was free flowing with an average speed of 54 miles per hour, although buses and carpools encountered some delays in crossing the three general traffic lanes to enter and leave the diamond lanes. Overall, 3+ carpools and buses typically maintained average speeds that were 7-10 mph faster than before the diamond lanes were introduced.

Low occupancy vehicles in the general traffic lanes did not fare as well. Even though peak period average speeds of vehicles in the general traffic lanes improved as the project progressed to approximately 41 mph, they never reached their pre-project average of 45 mph. At the time the project was ended by court order, westbound travel times during the PM peak period were more than one minute longer than pre-project levels and eastbound trips during the AM peak period were more than four minutes longer. Average speeds on the surface streets

Figure 9-2.

Overview of the Santa Monica Diamond Lane Project Area



Source: UMTA/TSC Project Evaluation Series, <u>The Santa Monica Diamond Lanes Volume I: Summary</u>, Final Report, 1977.

paralleling the freeway also decreased slightly during the demonstration, dropping by about 4.5 percent, as some former freeway users were diverted from the freeway to parallel surface streets.

The life span of the diamond lane demonstration project was too short, about four months, for a "fair test" of the concept. Evidence from a somewhat longer-term project in Boston indicates that general traffic travel times and speeds might well have eventually returned to pre-project levels had the project been allowed to continue, and that the benefits to Los Angeles residents might have been positive.* It takes travelers time to adapt to new choices and conditions created by HOV lanes and to change their behavior. Four months was probably too short a time for most commuters to adjust, particularly given the serious implementation problems that were associated with the diamond lane project.

Effects of Ramp Metering

Prior to the diamond lane project, approximately 30 Santa Monica Freeway on-ramps were equipped with traffic signals to control the number and spacing of cars entering the freeway during peak hours. Twelve of these ramps, moreover, had bypasses that gave buses and 2+ carpools preferential access to the freeway. Metering rates on most of the access ramps were changed during the week preceding implementation of the diamond lanes.

Table 9-1 provides information on cycle times, average queue lengths, and average waiting times for the 25 metered ramps on the segment of the Santa Monica Freeway included in the diamond lane project, both before and during the project. The table also indicates whether the ramp had a bus and carpool bypass. The effects of the re-timing of the ramp meters is clearly evident from Table 9-1. In the case of the Centinela inbound ramp, for example, the cycle length was increased from six seconds (10 cars per minute) before the project to 20 seconds (three cars per minute) during the project. As a result, the average queue length increased from five cars to 16 cars, and average waiting time to enter the freeway increased from one-half minute to nearly six minutes.

As the data shown in Table 9-1 indicate, major timing changes relative to pre-project conditions, i.e. cycle changes of greater than 100 percent, were made for several of the meters. In most cases, these cycle changes increased the waiting times for motorists wishing to use the freeway. Despite attempts to fine-tune the system as the project continued, average delays at the metered ramps used by the bulk of entering traffic increased by one to five minutes per car over the life of the project. At the 12 entry ramps with bus/carpool bypasses, these vehicles saved between two and seven minutes per trip during the diamond lane demonstration, in addition to time savings from using the diamond lane itself.

Considering both ramp delays and slower freeway speeds, increases in average eastbound (AM) trip times for low occupancy vehicles were as high as six minutes per trip (for those using the entire 12 miles of freeway). Similarly, travel times for westbound travelers in the PM peak increased by as much as seven minutes per trip, again for vehicles entering the freeway near the CBD, and traveling the full 12 mile length of the diamond lane.

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* A similar type of project was implemented in Boston for six months in 1977. Speeds in the general purpose freeway lanes were equal to or less than pre-project levels by the end of the project(UMTA/TSC, 1978, p.32).

Table 9–1. Cycle Times, Queue Length, and Waiting Times for Santa Monica Freeway Ramps Before and During the Diamond Lane Project

Ramp	HOV Bypass	Cycle Time (sec.) Before	Cycle Time (sec.) During	Queue Length (cars) Before	Queue Length (cars) During	Avg. Wait (min.) Before	Avg. Wait (min.) During
Eastbound (6–10 AM)							
Lincoln	No	5	6	28	41	2.1	4.1
Loverfield	Yes	0	9	0	26	0.0	4.0
Centinela	No	6	20	5	16	0.5	5.8
Bundy	Yes	7	8	13	23	1.7	3.5
Overland	No	8	17	27	20	3.5	5.7
Manning	Yes	8	18	27	29	3.9	8.7
Robertson	No	12	20	21	24	4.0	7.7
La Cienega	No	20	20	12	13	4.2	4.8
Venice	Yes	19	20	13	14	4.4	4.9
Washington	No	11	14	37	21	7.5	3.8
La Brea	No	11	13	28	13	5.2	3.2
Crenshaw	Yes	7	7	25	24	3.1	2.5
Arlington	No	7	7	8	5	0.8	0.3
Western	Yes	4	6	3	8	0.3	0.6
Normandie	No	8	9	3	NA	0.9	NA
Vermont	Yes	6	9	3	5	0.3	0.5
Hoover	No	18	18	13	NA	4.2	NA
Westbound (3–7 PM)							
La Cienega	No	5	12	33	26	5.3	7
Fairfax	Yes	10	20	11	14	2.1	5.9
Crenshaw	Yes	13	20	6	8	1.5	3.2
Arlington	No	10	20	3	2	0.8	1
Western	Yes	12	18	3	7	0.8	2.1
Normandie	No	12	20	6	9	1.5	2.9
Vermont	Yes	12	20	17	22	3.1	8.2
Hoover	Yes	8	20	18	19	2.3	6.9

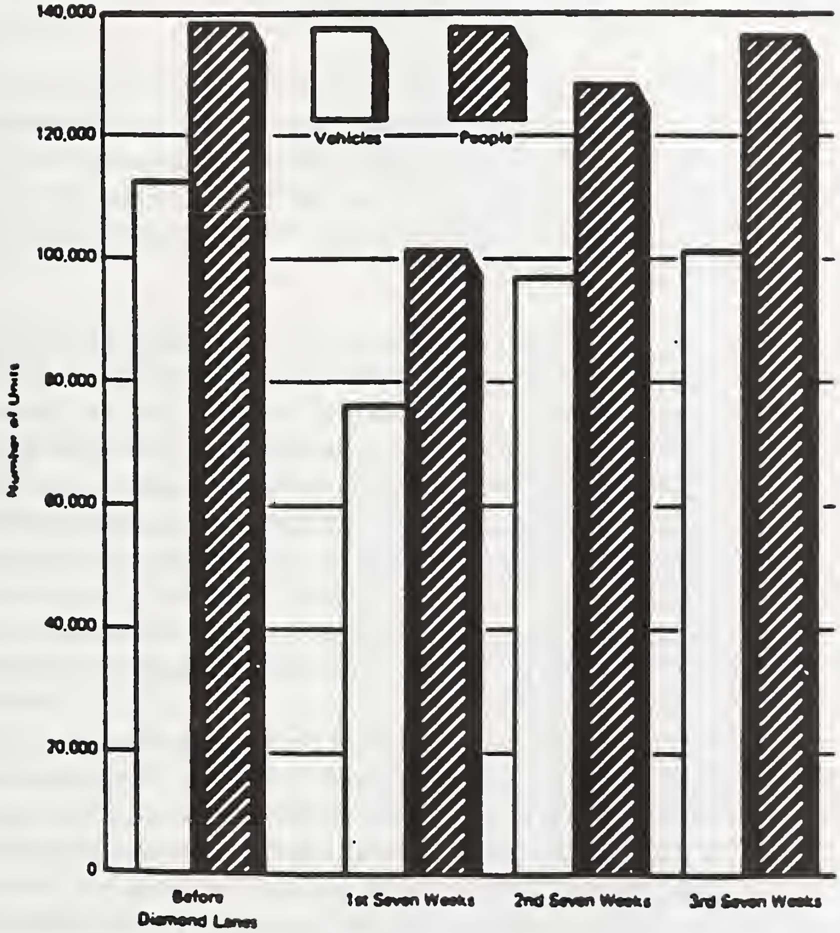
Source: Billheimer, et.al. (1977).

The delays for low occupancy vehicles at ramps with bus/carpool bypass generally exceeded the differential travel times between the diamond lane and the general traffic lanes for vehicles using the full length of the facility. According to the SYSTAN, Inc. (1977), if Caltrans engineers had been given more time, they would likely have been able to achieve ramp waiting times similar to pre-project levels by adjusting meters and/or adding new ones. Unfortunately, the short duration of the project and Caltrans limited prior experience with ramp metering, created a situation where ramp waiting times increased for a large percentage of the vehicles entering the Santa Monica Freeway.

Carpool Formation and Bus Ridership

The higher travel times initially experienced by the users of low occupancy vehicles led to significant shifts in traffic patterns. The data in Figure 9-3 show how total vehicle and total

Figure 9-3. Vehicle and People Throughput on the Santa Monica Freeway at Crenshaw Blvd. (Seven Hour Peak, Both Directions)



Source: UMTA/TSC Project Evaluation Series, The Santa Monica Diamond Lanes Volume I: Summary, Final Report, 1977.

person trip volumes changed over the life of the diamond lane project. These data strongly suggest that if the demonstration had continued, vehicle volumes would have remained slightly below (by about 10 percent) pre-project levels, but the number of person trips served by the freeway would have reached or exceeded pre-project levels.

In the first seven weeks of the diamond lane demonstration, the total number of person trips using the Santa Monica Freeway during the peak seven hours dropped from 140,000 to 100,000, while vehicle throughput dropped from about 116,000 to 75,000 (see Figure 9-3). These declines reflected the combined effects of carpool formation, increasing bus ridership, and the diversion of LOVs to surface streets. By the end of the demonstration, however, the number of people using the freeway had risen to within two percent of pre-project levels, and vehicle volumes were only 10 percent below pre-project levels.

Part of this adjustment in peak period use of the freeway was achieved by changes in departure times for users of low occupancy vehicles; thus, the number of vehicles using the freeway during the off peak hours, 10:00 AM - 3:00 PM (when the diamond lanes were not in force), increased by between two and six percent over pre-project levels. This suggests that many commuters elected to alter their travel time or routes, rather than face the much-publicized congestion during diamond lane operating hours.

Prior to the diamond lane project, each lane of the Santa Monica Freeway carried approximately 1,800 vehicles per hour during peak hours. In contrast only about 300 vehicles per hour used the diamond lane in the peak eastbound (AM) direction and 500 vehicles per hour used it in the peak westbound (PM) direction. Thus only 20 to 30 percent of the diamond lane's vehicle capacity was used during peak hours, making the lanes appear empty, especially in comparison to the heavily congested adjacent lanes. Despite the impression of emptiness, by the end of the project the diamond lanes were actually carrying as many persons as each of the adjacent general purpose traffic lanes. Table 9-2 provides further information on changes in traffic patterns and 3+ carpool and bus ridership that occurred during and after the diamond lane project; these measurements were made at a point close to the Los Angeles CBD.

The diamond lane project might have had more benefits and been more acceptable to the public if Caltrans had permitted 2+ carpools to use the facility. Two person carpools accounted for approximately 17 percent of all vehicles using the general traffic lanes of the El Monte Freeway in 1976. If the fraction was the same for the Santa Monica Freeway, and if all 2+ carpools had used the diamond lanes, between 1,200 and 1,400 vehicles per hour (900 2+ carpools plus the 300-500 3+ carpools and buses that were already using the diamond lane) would have used the lanes during peak hours.* Caltrans engineers estimated that the diamond lane capacity , assuming a speed of 50 mph, was 1,600 PCUs (passenger car equivalent units). Thus, even if peak hour use reached 1,600 PCUs, diamond lane speeds at 50 mph would have been only slightly less than the 53 mph speeds which prevailed during the demonstration.

Carrying these hypothetical calculations a step further, a shift of all 900 two-person carpools to the diamond lanes, assuming no change in total vehicle volumes, would have reduced

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* Seventeen percent of 1,800 vehicles per hour on each general purpose freeway lane equals 306 two person carpools per lane during the peak hours. Since there are three general purpose freeway lanes, the total number of two person carpools using the Santa Monica Freeway is 918 (306 x 3).

Table 9–2. Average Daily Vehicle and Passenger Statistics of Santa Monica Freeway at Crenshaw Boulevard
(Seven–Hour Peak Period, Both Directions of Travel)

		During Diamond Lane Project			
Statistics	Before Project	First 7 Weeks	Second 7 Weeks	Final 7 Weeks	After Project
Total Vehicles					
Number	113,135	76,738	97,197	101,678	112,059
% Increase (decrease)	--	–32%	–11%	–10%	–1%
Total People					
Number	138,873	101,643	128,180	136,421	140,507
% Increase (decrease)	--	–27%	–8%	–2%	1%
Bus Ridership					
Number	1,171	3,092	3,569	3,810	2,916
% Increase (decrease)	--	164%	205%	225%	149%
Passengers/Vehicle					
Ratio	1.23	1.32	1.32	1.34	1.25
% Increase (decrease)	--	8%	7%	9%	2%
Three–Person Carpools					
Number	3,479	4,345	4,923	5,749	3,652
% Increase (decrease)	--	25%	42%	65%	5%

Source: UMTA/TSC Final Report, September, 1978

the number of vehicles in the general traffic lanes to 1,500 per lane per hour, a level somewhat below pre-project conditions. Under these circumstances, nearly "ideal" conditions would have prevailed on the diamond lane and volumes on the general traffic lanes would have been reduced enough to allow travel time and speeds to improve during peak periods.*

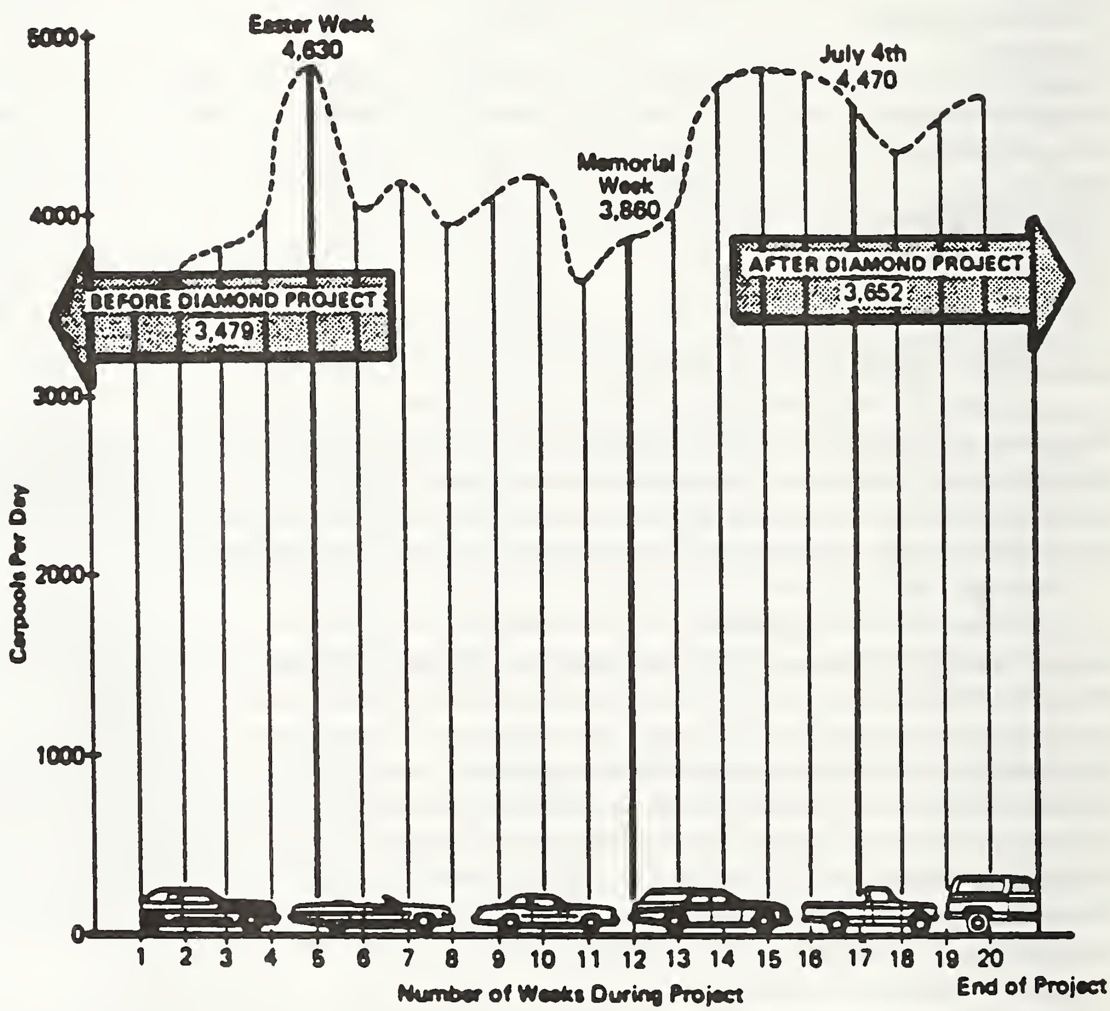
As the carpool usage data in Figure 9-4 reveal, the number of 3+ carpools using the diamond lanes at the end of the demonstration was 65 percent greater than before the project was implemented. The growth of 3+ carpools was relatively steady except, as Figure 9-4 indicates, carpool usage was higher during vacation periods. Carpoolers using the diamond lanes were surveyed about their reasons for forming carpools. Most, 63 percent, of all carpools gave financial savings as their primary reason for carpooling, and only 30 percent of the <u>new</u> carpools gave the diamond lanes as their primary reason for forming a carpool. After the diamond lanes were discontinued, the number of carpools declined to within five percent of the pre-project levels; the finding suggests the time savings provided by the diamond lanes were an important incentive for carpool formation.

As the data in Figure 9-5 reveal, both bus and carpool person trips increased dramatically during the demonstration, where both bus and carpool trips are peak period trips in both directions for the entire freeway (diamond lanes plus general purpose freeways lanes). Bus ridership increased by 225 percent during the experiment, 3+ carpool use increased by 65 percent for the same period. Three quarters of bus ridership growth occurred in the first seven

* This, of course, ignores the impact of traffic attracted from parallel routes by the improved conditions. A more likely outcome would have been much larger vehicle and person trip volumes in the diamond lanes, little or no change in the volumes and speeds in the general purpose freeway lanes, and much greater acceptance of the diamond lanes.

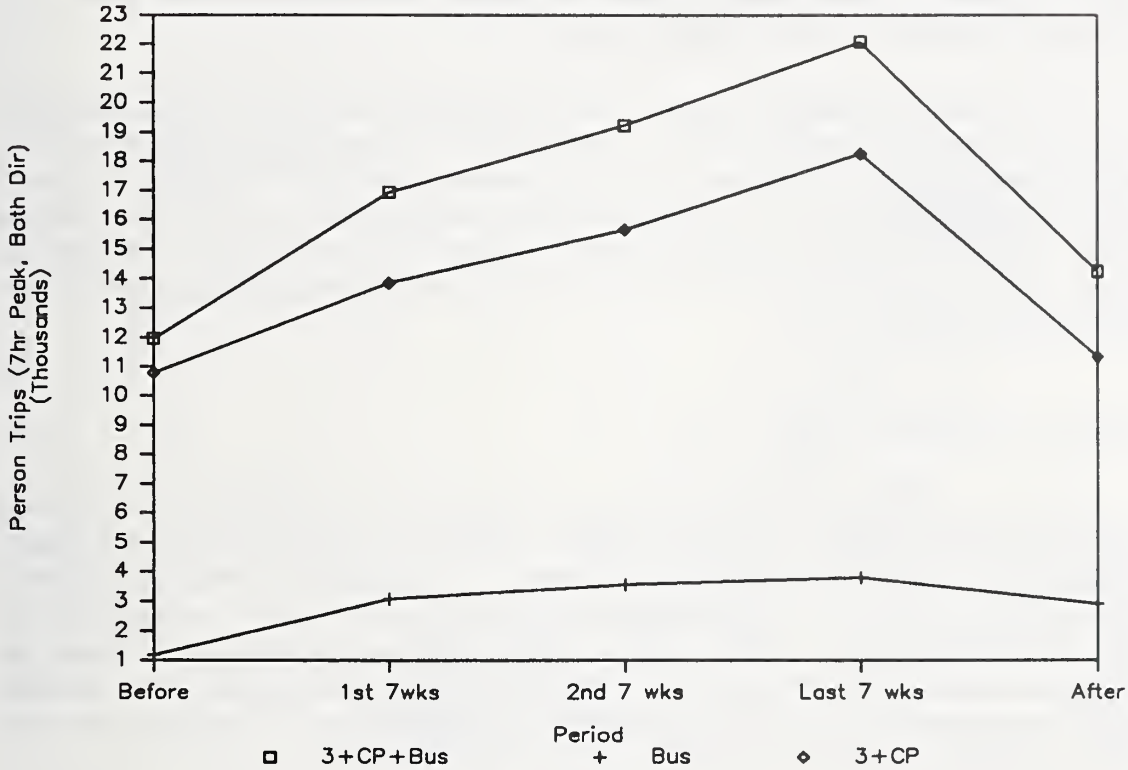
Figure 9-4.

Carpools Using the Santa Monica Diamond Lanes Before and After the Demonstration by Week



Source: UMTA/TSC Project Evaluation Series, The Santa Monica Diamond Lanes Volume I: Summary, Final Report, 1977.

Figure 9-5. Person Trips by Bus and 3+ Carpools on the Santa Monica Freeway Before, During and After the Diamond Lane Project (Seven Hour Peak, Both Directions)



weeks of the 21 week demonstration, a finding that suggests that more extensive coverage and increased schedule frequency had more effect on bus ridership than the time savings and reliability improvements provided by the meters and the diamond lanes. Further support for this proposition is provided by the fact that ridership on the four routes that existed before the diamond lane project increased just 28 percent, while bus ridership grew by 38 percent between the project's first seven weeks and the last seven weeks. Furthermore, total ridership for all freeway express buses declined by only 23 percent after the project was discontinued.

Both the SCRTD and the Santa Monica Municipal Bus Lines (SMMBL) began new services at the time the diamond lanes were implemented. The number of integrated, i.e. combined feeder express, bus routes between the CBD and West L.A. for example, was increased from four to eight. With these route expansions more then twice as many Westside CBD workers lived within walking distance of express service than before the project began. On the first day of the demonstration 74 express bus trips were provided between the Westside area and the Los Angeles CBD during the AM peak period; this is more than a four-fold increase over pre-project levels.

Major expansions in bus system coverage, shown in Figure 9-6, and increases in frequency would have increased transit ridership even without the diamond lanes. The diamond lanes, however, complemented these service expansions by increasing the speed and reliability of both new and existing services. Travel time for pre-project express bus services fell by almost 20 minutes during the demonstration project, i.e. from 57 minutes to 38 minutes for a 15 mile route.* Diamond lane buses, moreover, were more reliable, i.e. had better on-time performance, than buses using other freeways or surface streets.

In general, as the data in Figure 9-7 reveal, the Santa Monica express buses attracted significant numbers of former automobile drivers during the project, and an overwhelming majority of these expressed satisfaction with the bus services. By the end of the demonstration project, the eight feeder/express routes came close to meeting the project target of carrying 30 percent of the CBD destined trips originating within walking distance of a bus line. Ridership on the three new park and ride routes, however, fell far short of expectations and they were discontinued by September 1, 1976.

Monetary Costs of the Project

The total cost of the Santa Monica Diamond Lane Demonstration Project in 1989 dollars was approximately $6 million, of which $2.4 million was spent on data collection and evaluation and $1.8 million was used to subsidize bus operations.** No additional monetary costs were incurred by SCRTD, Caltrans or the California Highway Patrol; additional police officers, however, were shifted temporarily from other duty stations to the diamond lanes. Of course, the temporary reassignments presumably entailed some opportunity costs and a comprehensive cost-effectiveness analysis of the project would have to include them. Caltrans also spent approximately $730,000 on marketing and public information for the project.

Subsidies for increased bus services were a major component of project cost. Prior to the systemwide fare increases introduced by SCRTD and SMMBL in July and August of 1976, the average fare in 1989 dollars for diamond lane bus services was about $0.81 per trip. After the fare increases, which seemed to have had little impact on the demand for service on the feeder/express routes, the average fare in 1989 dollars was approximately $1.21 per trip.*** Ridership on park and ride services was far more sensitive to fares, and sharp ridership declines in the aftermath of a fare increase convinced SCRTD to discontinue these already disappointing routes.

Operating costs per rider in 1989 dollars during the project averaged $7.06 for SCRTD and $3.08 for SMMBL. These averages disguise some productivity improvements as per rider

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* These 19 minute time savings includes the time buses saved at the preferential by-pass lanes at metered entry ramps to the Santa Monica Freeway.

** All dollar figures, unless otherwise noted, are in 1989 dollars. Construction costs are converted into 1989 dollars using the ENR Construction Cost Index. All other costs are indexed using the GNP Implicit Price Deflator.

*** Unfortunately because the diamond lane project ended in early August it is probably impossible to quantify the independent effect of this fare increase on transit ridership. As we stated earlier, however, ridership decreased by only 17 percent after the project ended. If we attribute this entire decrease to the fare increase (rather than to an increase in travel time and decrease in on-time reliability) then the implied price (fare) elasticity of demand for express bus routes on the Santa Monica Freeway was about -0.41.

Figure 9-6.

Diamond Lane Bus Lines, March 15, 1976

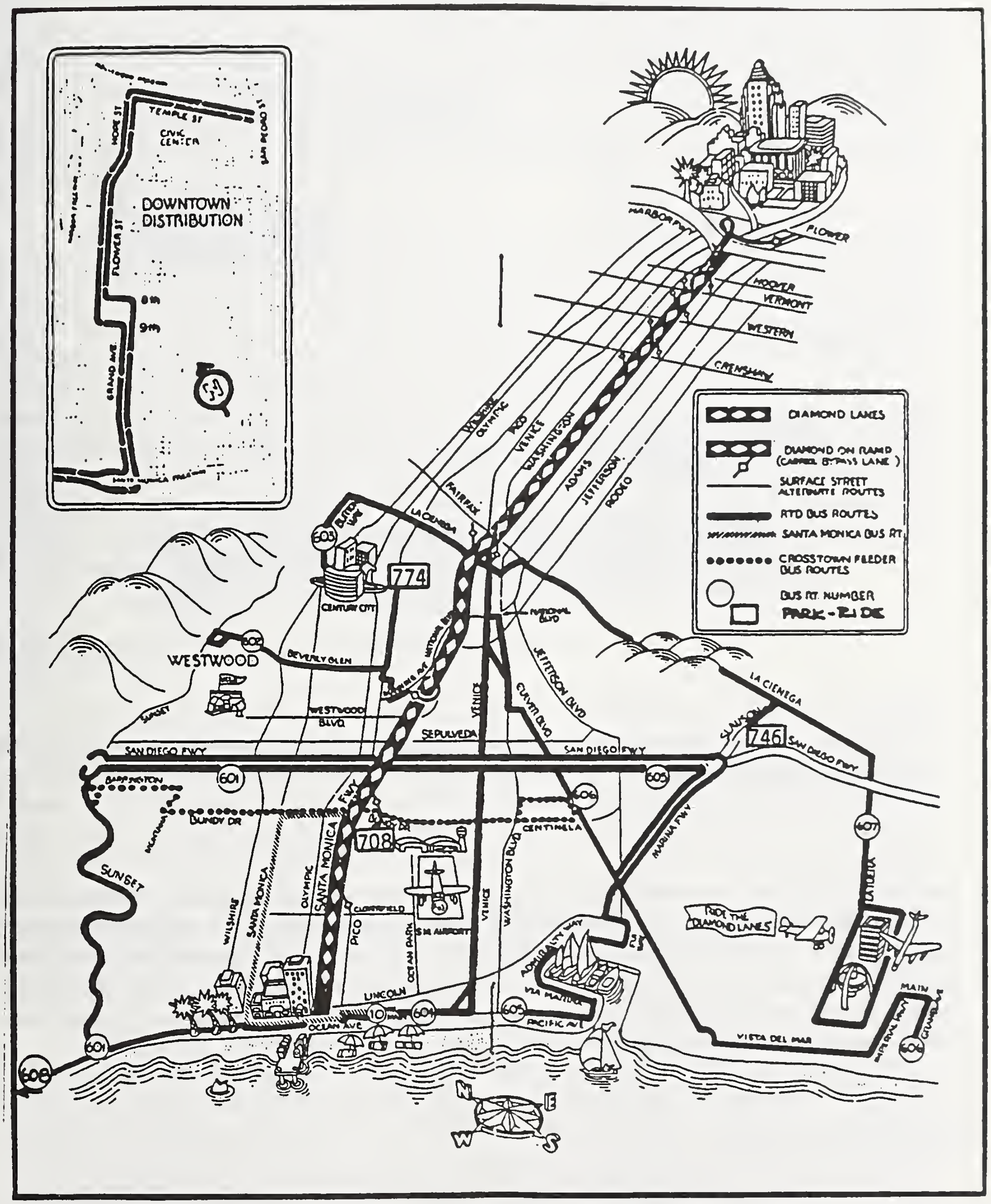
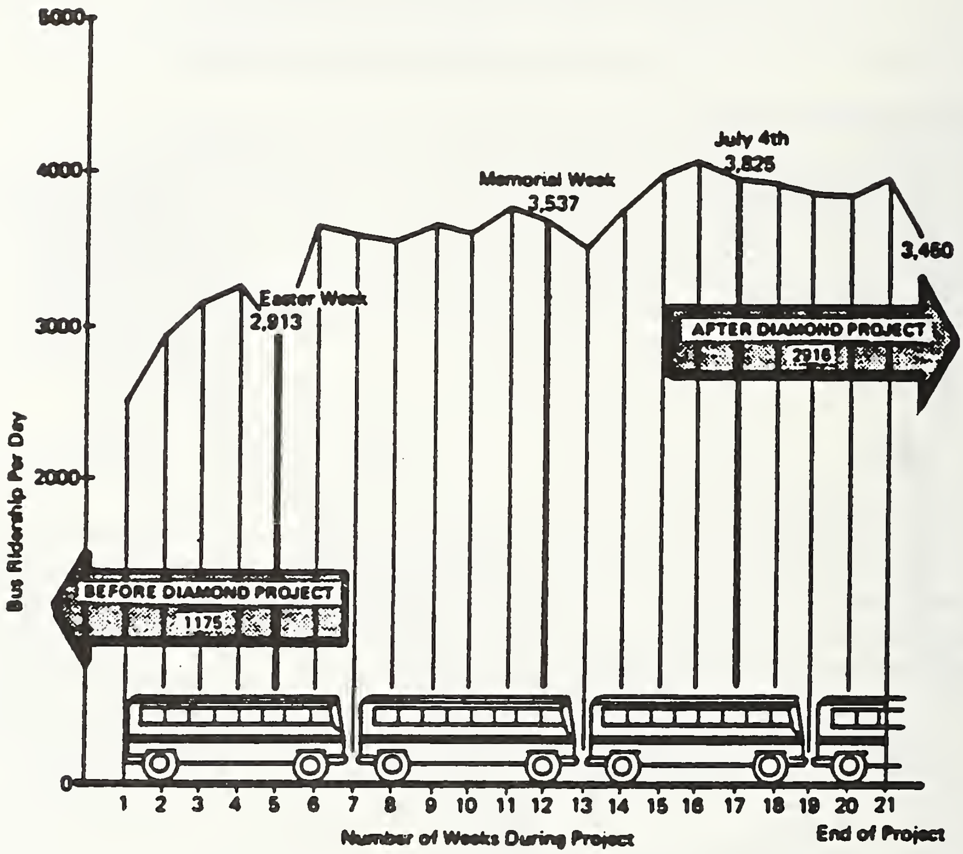


Figure 9-7. Average Daily Peak Period Bus Ridership on All Santa Monica Freeway Project Routes (Seven Hour Peak, Peak Direction Only)



Source: UMTA/TSC Project Evaluation Series, The Santa Monica Diamond Lanes Volume I: Summary, Final Report, 1977.

costs for SCRTD routes declined from $8.09 to $5.06 as SCRTD eliminated or pruned unproductive routes in the course of the project. Even so, Santa Monica Freeway express bus routes had relatively high per rider cost compared to other SCRTD routes. These higher costs per trip were caused by long average trip lengths, nearly empty backhauls, and the difficulty of generating more than one peak-period run per bus, characteristics which unfortunately are inherent features of such express bus services.

Enforcement and Safety

Non-barrier separated, concurrent flow reserved lanes are notoriously difficult to enforce and vulnerable to accidents. In an effort to "get off on the right foot," the California Highway Pa-

trol doubled the number of officers assigned to patrol the Santa Monica Freeway during the first weeks of the project.

Enforcement activities remained at above normal levels for the life of the project and the officers assigned to the freeway issued substantially more violations per man-hour than was true before the time the diamond lanes were implemented. An average of 151 warnings and citations were issued daily, a number that was more than four times projected pre-demonstration levels. In addition, in spite of the existence of a wide median where violators could be stopped and cited, enforcement efforts adversely affected other traffic on the freeway. The use of the median for enforcement reduced the capacity of the general purpose freeway lanes, especially the lane immediately adjacent to the diamond lane. Despite aggressive enforcement, violation rates remained in the 10 to 20 percent range, with most of the violations occurring at the fringes of the diamond lane operating times.

An increase in accidents was one of the most disturbing aspects of the diamond lane project, as the number of accidents per week more than doubled relative to pre-project levels. Fifty-nine accidents occurred during the first week of the demonstration. Accident rates subsequently declined, but they still averaged 25 accidents per week for the entire 21 weeks of diamond lane operation. Even allowing for start-up problems, accident rates on the Santa Monica Freeway were much higher than on other freeways. Approximately 18 accidents per week occurred during peak hours during weeks 11 to 21 of the project; this rate is more twice the pre and post project levels of six to eight accidents per week. Almost 80 percent of the additional accidents occurred in Lane 2, the general purpose freeway lane adjacent to the diamond lane. Caltrans and UMTA observers felt that the high incidence of accidents in Lane 2 was caused by frequent movements in and out of the diamond lanes and the large speed differential between the diamond lane and the remaining three general purpose freeway lanes.

Media Coverage and Public Response

The Santa Monica Freeway diamond lanes were an immediate media event, prompting frequent newspaper articles and editorials, radio and television coverage, public debate, and lawsuits. Media coverage of the project was generally unfavorable, and this adverse publicity was clearly a major factor in shaping the public's perceptions and attitudes toward the reserved lanes. In the 10 month period, January through October 1976, three major Los Angeles daily newspapers published about 50 articles and editorials on the project. This newspaper coverage was highly negative, using phrases such as "chaos on freeway," "diamonds don't glitter," and "sin and the diamond lanes." Four constantly recurring themes were "operational failures of the project," "aspects of coercing disincentives," "bureaucratic recalcitrance," and the "lack of credibility of published data."

Project planners recognized from the outset that the diamond lane project would be a "hard sell" and would likely be unpopular with commuters. In an effort to foster a positive attitude toward the project and increase the rates of bus use and carpooling, project planners organized an extensive marketing campaign to promote bus and carpool use and educate the public about the project's goals and achievements. Given the extent of pre-project advertising, it is doubtful that many regular freeway users were unaware of the opening of the diamond lanes. The commuters did have reason to be surprised, however, by several unannounced changes in the pro-

ject, including last minute adjustments of ramp meter rates and the closing of a slip ramp at the interchange of the Harbor and Santa Monica Freeways near the CBD.

An avalanche of negative publicity and public outcry following a disastrous first day of the diamond lanes operations drowned out the sponsors carefully planned advertising campaign. Surveys, interviews, telephone calls, newspaper polls, and public hearings all indicated an overwhelming negative public response to the diamond lanes. Eighty-six percent of corridor drivers interviewed in an extensive survey, including the majority of carpoolers, reported that they felt the diamond lanes were either harmful or of no benefit whatsoever.

Public reaction and media criticism were accentuated by the frequent, vocal opposition of several city and county officials. Opposition to the project ranged from largely constructive criticism by some officials who worked closely with project personnel in efforts to make the diamond lanes more acceptable to their constituents, to unconstructive attacks.

It would be unfair, however, to place all of the blame for hostile public opinion on the media and a few public officials. It is unlikely that negative media reports alone would have produced such a uniformly negative and strong a public response to the project had the initial impacts of implementing the diamond lanes not been so adverse. Less draconian changes in ramp meters, the use of a 2+ rather than a 3+ carpool criteria, and a more effective enforcement program very likely would have softened public opposition to the diamond lanes. Of these measures the use of a 2+ criteria would very likely have had the most effect. A less virulent initial response to the project might, in turn, have given Caltrans the time needed to demonstrate the usefulness of the diamond lane concept.

Preferential Bypasses at Metered Ramps

Ramp meters are a relatively low-cost modification to highway access ramps which can increase effective highway capacity and, if combined with bus/carpool bypasses, can encourage greater transit use and carpool formation. Ramp metering improves freeway traffic flow by restricting the rate at which cars enter the freeway. Caltrans uses both fixed time metering, based on historically determined rates of freeway traffic flow, and traffic responsive meters linked to electronic surveillance devices. Metering vehicles can increase effective highway capacity by preventing the breakdowns which frequently occur when demand too closely approximates capacity.

Southern California has by far the largest number of metered freeway ramps and associated HOV bypass lanes of any urbanized region (Southworth and Westbrook, 1985). Caltrans maintains 714 metered ramps throughout California, and 224 of these have bus and carpool bypass ramps; District 7 (the Los Angeles region) had implemented 215 of bus/carpool ramp bypasses in 1988. While Robert G. Goodell in an 1976 study of the first 13 HOV ramp bypasses in Los Angeles may have been a bit too enthusiastic about the benefits of bus/carpool ramp bypasses, his conclusions are nonetheless relevant. Goodell states:

> ramp bypasses do form carpools. They also serve as a substantial time saver for passengers of the 127 buses that use the bypasses daily. ...There will be approximately 1,000 metered ramps in the Los Angeles area in the next 5 to 7

> years. ... If the existing 13 ramps are any indication of the effectiveness of this concept, then 50,000 (23 percent of 200,000) new carpools could be formed by installing 250 bypasses at a cost of $1.5 million dollars (or $2.9 million in 1989 dollars) (Goodell, 1976, p.10).

While Goodell's method of estimating the number of carpools that would be induced by ramp meters and bypasses is both somewhat vague and most likely overly optimistic, his observations are nonetheless qualitatively correct. As our discussion of ramp meters on the Santa Monica Freeway suggests, ramp metering can improve traffic flow, and bus/carpool bypass lanes may provide buses and carpools with substantial time savings relative to low-occupancy vehicles; buses and carpools using the Santa Monica Freeway saved three and eight minutes per trip during peak hours (UMTA/TSC, September, 1977, p. 22).

Of the 215 ramp bypass lanes currently operating in the Los Angeles area, 75 are metered. In most instances, these ramp bypasses are open to buses and 2+ carpools. Early evaluation of the first 30 ramp bypass lanes installed in the Los Angeles area indicated that the ramps encouraged carpool formation. Carpools increased by more than 30 percent in the corridors with ramp bypass lanes, and led to slightly more people (4.6 percent) being carried in slightly fewer cars (2 percent), raising vehicle occupancy rates from 1.23 to 1.32 persons (Caltrans, 1978, pp.24-25).

There is widespread agreement among California's transportation planners that ramp metering and bus and carpool bypasses should be seriously considered whenever new HOV lanes are implemented. Some even argue that, in spite of the high (16 percent) violation rates of the ramp bypass lanes by single occupant vehicles, a comprehensive ramp metering program with HOV ramp bypasses would eliminate the need for additional HOV facilities in the L.A. area. Most transportation analysts and planners in Southern California are of the opinion, however, that the cycle times and delays for many ramps that would be required to maintain free-flow conditions on all freeways would result in unacceptably long queues at many ramps, and adversely affect conditions on many local streets. Nonetheless, the Southern Californian experience with ramp metering and HOV bypass lanes is quite positive, and suggests such facilities should be provided on any heavily used freeway where their installation and enforcement can be achieved at reasonable cost.*

Commuter Lane Projects

For almost 10 years after the Santa Monica Diamond Lane experience, no new HOV lanes were implemented in the Los Angeles region. The HOV projects which were subsequently implemented, moreover, were described by area planners as "commuter lanes," and were carefully designed to avoid the problems that arose with the implementation of the Santa Monica Freeway Diamond Lane.

In June 1985, Southern California's first HOV lane demonstration project since the 1976 opening of the Santa Monica Diamond Lane, began operating on the eastbound Artesia Free-

* Both the SCAG (1987) and Caltrans (1985) include ramp metering and by-pass lanes as an integral part of their long-range transportation management plans.

way (Route 91). Six months later, a second commuter lane project was opened on the Newport Freeway (Route 55). These projects became permanent in 1987, and a third commuter lane, located on I-405 in Orange County from I-5 and I-605, has recently begun operations.* Plans for a number of other HOV lane projects are in various stages of development and approval.

The term 'commuter lane' is used to describe HOV facilities which are primarily carpool facilities, with little bus service. The two Los Angeles region commuter lanes discussed below were implemented by providing an additional lane, rather than by taking away an existing general purpose freeway lane, as was done in the Santa Monica Diamond Lane Demonstration Project. In addition, in an effort to improve safety, the L.A. and Orange County commuter lanes provide relatively few locations where vehicles can legally enter or leave the commuter lanes. This again is in contrast to the Santa Monica Diamond Lane project, where carpools and buses were permitted to enter and leave the HOV lanes at any point. The success of Southern California commuter lanes has further strengthened, perhaps unfairly, the belief that HOV lanes should never be created by taking away an existing freeway lane. Caltrans current policy is that HOV lanes will only be provided by adding lanes, regardless of whether or not taking an existing lane from mixed-flow traffic would be more cost-effective (SCAG, 1987, Section VI).

The growing support for HOV facilities in Southern California reflects the worsening congestion on the region's freeways. Transportation planners in the area have long recognized that HOV lanes have the potential to serve many more people than unrestricted general purpose freeway lanes, and, more importantly, provide reserve capacity to accommodate growing trip demands. As congestion in the general purpose freeway lanes becomes worse, more commuters are induced to make their trip by bus or to form carpools, and the number of trip makers served by the HOV lanes during peak periods increases.

Table 9-3 presents an example developed by SCAG (1987) analysts that is meant to demonstrate the effectiveness of commuter lanes as a method of adding peak period capacity to existing freeways. This example compares the increase in person carrying capacity obtained by adding a commuter lane to an existing 8-lane freeway to the increase that would be obtained by adding a general purpose freeway lane. Starting with four lanes in each direction, 2,000 vehicles per lane per hour, and 1.2 persons per car, Southern California Association of Governments (SCAG) analysts obtain the peak hour/peak direction capacity for an eight lane freeway, without HOV lanes, of about 8,000 vehicles and 9,600 persons per hour. They assume further that adding a general purpose freeway lane would increase the freeways capacity to 10,000 vehicles and 12,000 persons per hour. In contrast, they find that adding a commuter lane would increase the freeway's total directional-hour capacity to 9,600 vehicles and 13,120 people, assuming that the capacity of the HOV lane is 1,600 vehicles per hour and the average occupancy rate is 2.2 persons per car. Although the freeway with HOV carries 400 fewer vehicles than a fifth general purpose freeway lane would, it serves 1,120 more people.

SCAG's example only hints at the potential of HOV lanes. Simply using a 3+ rather than a 2+ carpool criteria, for example, would increase average occupancy in the HOV lane to more than 3 persons per car and increase the freeway's person carrying capacity to more than 14,400

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* The first phase of construction, from SR 55 in Orange County to SR 605 in Los Angeles County, is scheduled for completion in late 1989. The second phase, south of SR 55 to the confluence with I-5, is scheduled to be operational in the summer of 1990 (SCAG, 1987).

Table 9–3. Freeway Capacity Comparison: Added Mixed Lane versus Added HOV Lane

	Vehicles/Hour	Occupancy	Persons/Hour
Existing 4–lane freeway	2,000	1.2	2,400
	2,000	1.2	2,400
	2,000	1.2	2,400
	2,000	1.2	2,400
Total	8,000		9,600
4–lane freeway plus	2,000	1.2	2,400
mixed–flow lane	2,000	1.2	2,400
	2,000	1.2	2,400
	2,000	1.2	2,400
	2,000	1.2	2,400
Total	10,000		12,000
4–lane freeway plus	1,000	2.2	2,200
HOV lane (short–term)	2,000	1.1	2,200
	2,000	1.1	2,200
	2,000	1.1	2,200
	2,000	1.1	2,200
Total	9,000		11,000
4–lane freeway plus	1,600	2.2	3,520
HOV lane (long–term)	2,000	1.2	2,400
	2,000	1.2	2,400
	2,000	1.2	2,400
	2,000	1.2	2,400
Total	9,600		13,120

Source: SCAG (Southern California Association of Governments). (1987).

persons. The actual numbers carried would, of course, depend on the demand for 3+ carpools. In addition, if the pattern of commuting in the corridor was conductive to significant transit use, an increase in the number of bus riders using the HOV lane would dramatically increase the lane's and freeway's effective capacity. With a 15 percent transit mode split on the freeway, the bus-carpool lane could accommodate 141 buses and 1,360 carpools and the effective person carrying capacity of the freeway would become 19,320 persons per hour, assuming each bus carries 40 persons.

Caltrans' reports on the early experience of the Route 91 and Route 55 commuter lanes are extremely encouraging. Average vehicle occupancy on the Route 91 commuter lane during 1986 was 2.2 persons per vehicle; Caltrans' analysts report that "at an average of 1,450 vehicles per hour carrying 2.2 people per vehicle, the commuter lane serves 3,190 people per hour at the peak hour. The other freeway lanes with 2,000 vehicles per hour carry only 2,200 people per hour. The Route 91 commuter lane thus carries 45 percent more people during the peak hour than the adjacent freeway lanes." Caltrans reports similar results for the Route 55 project, where the commuter lane is carrying 34 percent more people than the adjacent general traffic lane.

As Figure 9-8 shows, the Route 91 commuter lane extends eastbound for eight miles along the Artesia Freeway. It was implemented at a 1989 dollar capital cost of $220,000 (a mere $27,50 per mile) by simply allowing HOV's (in this case, vehicles with two or more occupants) to use the median shoulder during peak periods. When the commuter lane first opened, its hours were 3-7 PM, but in an effort to reduce the number of violations occurring during the period immediately before 3 PM, when there was significant congestion, the lane's hours were soon extended an hour to 2-7 PM .

A two-foot wide striped buffer area is all that separates the commuter lane from the general freeway lanes. It is illegal to cross this two-foot, striped buffer strip during hours when the shoulder is being used as a commuter lane. Two entry and two exit points to the commuter lanes are designated by breaks in the striping (openings in the so-called buffer area). No direct entry or exit ramps are provided into the commuter lane; HOV's must simply move into and out of the commuter lane at the two legal entry/exit points from the adjacent freeway lane.

The commuter lane is 11 feet wide with a two-foot inside shoulder, adjacent to the median. The width of the number-one general purpose freeway lane, the one next to the commuter lane, was reduced from 12 to 11 feet. Large signs on the top of the median barrier wall and on overpasses indicate when the commuter lane is open. These signs are changed twice a day and are augmented by signal-head indicators (red X's and green arrows).

Following an initial two month "break-in" period, peak hour use of the commuter lane increased from about 1,000 to approximately 1,500 vehicles per hour. The commuter lane carries approximately 3,300 persons (2.2 persons per vehicle) during an average peak hour; this compares to about 2,200 persons (1.2 persons per vehicle) in the adjacent freeway lanes.

Delays in the Route 91 corridor were significantly reduced by implementation of the commuter lane. Both the severity and duration of congestion on the general purpose freeway lanes declined, as carpools and vanpools shifted to the commuter lane. Travel times on the general purpose freeway lanes were initially reduced from 30-35 minutes to 15-20 minutes for the eight mile trip. Until recently, 2+ carpools using the commuter lane experienced little or no delay and their travel times averaged 8-9 minutes.

The design of Route 55's (Costa Mesa Freeway) commuter lanes is quite similar to the Route 91 commuter lane. In contrast to the Route 91 commuter lane which operates in only one direction, two lanes and two-way operations were provided on Route 55. The commuter lanes were created by restriping all the freeway lanes, reducing them in width from 12 feet to 11 feet, and by creating new lanes on each side of the median. The painted divider which separates the HOV lanes from adjacent general traffic use is only one-foot wide, even narrower than the two-foot buffer on Route 91. As shown in Figure 9-8, the Route 55 commuter lanes run north and south from just south of Route 91 to north of I-405 with a few exit and entry points along the way. The Route 55 facility began operation in November of 1985 and operates on a 24-hour basis for vehicles with two or more passengers; approximately 3,520 commuters in 1,600 vehicles use this facility in the afternoon peak hour.

Vehicle trips on Route 55 increased by 30 percent immediately after the commuter lane was opened, as peak usage of the southbound section grew from 5,400 to 7,000 vehicles per hour. AM peak period auto occupancy rates for all of Route 55 increased from 1.2 persons per

Figure 9-8.

Commuter Lanes on California State Routes 91 and 55

Source: Ropers (1986).

vehicle in 1985 before the commuter lanes were opened to 1.34 in 1987, after the lanes had been in operation for 18 months. This 11 percent increase in average occupancy rates, in combination with the 30 percent increase in vehicle volumes, translates into a 45 percent increase in the number of person trips served by this section of freeway during the AM peak.

According to surveys carried out by the Orange County Transit District, introduction of the Route 55 commuter lanes led to more than a doubling of the number of 2+ carpools using the freeway during the morning peak period from 332 to 653. The same survey indicated that two-thirds of the carpools using the commuter lane did not exist before the lane was opened. Some caution must be used in interpreting these data, however, since 18 months had elapsed since the commuter lanes were opened and some new carpools would have been formed even in the absence of the commuter lanes.

Successful efforts to minimize violation rates by vehicles with fewer than two occupants and enforce restrictions on access/egress to and from the commuter lanes were crucial elements in insuring the effectiveness of both the Route 91 and Route 55 commuter lanes. Caltrans coordinated the planning of priority lanes with the California Highway Patrol, which has responsibility for enforcement. Violation rates have been quite low on the commuter lanes; recent counts showed that violation rates during the PM period were only 4.3 percent for Route 91 and 5.9 percent for Route 55.

The relatively low violation rates for the commuter lanes are undoubtedly explained in large part by the use of the 2+ occupancy requirement. As a result of the heavy use of the commuter lanes, relatively few drivers in single-occupancy vehicles are tempted to illegally use them. As corridor demand increases, and the number of vehicles using the commuter lanes increases, speeds in the commuter lanes will begin to decrease, reducing the incentives for transit use and carpooling. This situation has already begun to occur for the Route 55 commuter lane where peak hour vehicle volumes have increased from about 1,000 during the first month of operation to over 1,600. Speeds will soon begin to suffer if they have not already. As a result, Caltrans is considering increasing the occupancy requirement from 2+ to 3+ to maintain the commuter lane travel time advantages and to preserve the incentive to form carpools. As we discuss in Chapter 10, when Houston METRO was confronted with a similar situation on the Katy Transitway, it was able to increase the vehicle occupancy requirement from 2+ to 3+ with little or no opposition. At the same time, METRO applied the 3+ criteria to only the AM peak period; it continued to use the 2+ criteria during the evening peak.

Buffer zone violations, vehicles entering and leaving the commuter lane at other than designated entry/exit points, are more common than occupancy violations, i.e. instances where vehicles with fewer than two persons use the lanes. Nearly a third of all Route 91 commuter lane users enter or leave the lane illegally, i.e. at points other than the authorized entry/exit points. Fortunately, the illegal crossings of the buffer zone appear to have resulted in few significant safety or operational problems thus far. Project planners feel that better signing and more stringent enforcement are the most promising way of reducing buffer zone violations.

Implementation of a program similar to Washington State's HERO program may be a promising approach to reducing both kinds of violations. HERO is a citizen-enforced commuter lane program which has had considerable success in Seattle (WSDOT, 1987). Initially, violation rates for Seattle's HOV lanes were very high, ranging from 17 to 38 percent. In 1984, the Wash-

ington State DOT (WSDOT) began asking motorists to report HOV violations to a well advertised HERO telephone number. An operator or a recording machine at this number records information provided by callers on the vehicle (license number, make of the car, and number of occupants) and the location, time, and date of the violation.

After determining where the reported vehicle is garaged, WSDOT sends a brochure explaining the purpose of the HOV lanes. If a second violation is reported for the same vehicle, a second brochure is sent along with a somewhat more pointed letter from WSDOT. If a third violation is reported, the Washington State Police (WSP) sends a letter to the registered owner. In addition, WSP contacts habitual violators by phone or in person. A citation is issued only after the WSP has observed a violation; HOV violations are considered moving violations with a fine of $37. The HERO program has been very effective. Depending on location, violations have dropped by 30 to 50 percent, and HOV lane violations have decreased by 36 percent overall.

In contrast to the Santa Monica Diamond Lane experience, the Southern Californian commuter lanes have met with strong public acceptance. Over 90 percent of all contacts from the public have expressed support for the projects. The most obvious differences between the commuter lanes and the diamond lanes are that the commuter lanes improved conditions on the general purpose freeway lanes rather than worsening them, and the commuter lanes are heavily used.

HOV Plans for Orange County

Orange County's low density and dispersed development is typical of much of the greater Los Angeles metropolitan area. Over the past 20 years, the county's character has changed from semi-rural to urban with the accompanying traffic and mobility problems. Traffic jams lasting several hours, with average speeds of less than 30 mph on the freeways, are increasingly common. Conditions are expected to worsen unless remedial actions are taken, as the number of daily trips made in the county are expected to grow from 6.8 million in 1980 to well over 10 million by the year 2000 (OCTD, 1986, p.1)

Orange County is currently planning an extensive transitway (HOV) system in an effort to increase the system's person carrying capacity. The plan would provide barrier-separated facilities for buses, carpools, and vanpools, generally in the median of freeway rights-of-way. The Orange County Transit District (OCTD) envisions an integrated system of transitways and commuter lanes serving Orange County's major activity centers, as a way of providing these growing centers with improved public transit and increasing the person carrying capacity of the county's freeways.

As Figure 9-9 illustrates, OCTD has proposed building a core 19.4 miles of barrier-separated transitways that would be connected to an additional 50-miles of commuter lanes. OCTD anticipates that both the proposed transitways and commuter lanes will be two-way facilities. OCTD makes the same distinction between commuter lanes and transitways as Caltrans. Specifically, commuter lanes are median HOV lanes separated from the general purpose freeway lanes by a painted buffer. No exclusive ramps are provided to connect the commuter lanes to adjacent streets or to other commuter lanes at freeway-to-freeway interchanges. The

Figure 9-9.

Relationship of Transitway System and Activity Centers in Orange County

Source: OCTD Report, 1986, page 7.

successful Route 55 project is cited as a representative example of a commuter lane, although the ill fated Santa Monica Diamond Lane could be considered a commuter lane as well.

Two critical differences account for the widespread acceptance of the Route 55 and 91 commuter lanes, as contrasted to the abysmal failure of the Santa Monica Diamond Lane. First, total freeway capacity was increased in the case of the Route 55 and 91 commuter lanes. Second, the use of a 2+ rather than 3+ carpool criteria for use of the HOV lanes insured that the Route 55 and Route 91 commuter lanes were heavily used.

Transitways, in contrast, are barrier-separated facilities, similar to those currently operating in Houston and the westernmost segment of the El Monte Busway. These facilities, typically located in freeway rights-of-way, are accessed by slip ramps or more expensive flyovers or T-ramps.

Description of Transitways

As Figure 9-9 illustrates, the proposed 19.4-mile transitway system would serve most of Orange County's major activity centers and would be connected to existing and proposed commuter lane facilities. The proposed transitways would consist of four major sections:

- SR 57 (Orange Freeway) from I-5 (Santa Ana Freeway) to SR 91 (Riverside Freeway).
- I-5 from Katella Avenue in Anaheim to SR 55 (Costa Mesa Freeway).
- SR 55 from I-5 to I-405 (San Diego Freeway).
- I-405 from Von Karman Avenue to Bear Street.

Employment in the eight activity centers shown in Figure 9-9 is expected to nearly double between 1985 and 2010. All eight centers are located within one mile of a major freeway and all depend heavily on freeway access. As planning for the transitway and commuter lane system has proceeded, OCTD has increasingly emphasized the importance of providing direct access between the transitways and eight major activity centers.

Estimated Ridership/Usage

OCTD's projections of transit and carpool demand for the segment of the proposed transitway that would be built in the SR 57 right of way, between I-5 and SR 55, are shown in Table 9-4. As these data indicate, public transit use of the transitway is projected at a modest 22,100 person trips per day in 2010. In contrast, between 52,700 and 123,600 daily person trips and 3,000 to 11,000 peak hour vehicle trips are expected to use the facility in carpools, depending on a 3+ or 2+ restriction respectively. The level of transitway carpool use in 2010 would depend on the occupancy criteria. OCTD's forecasts also indicate that the capacity of a number of transitway segments would be exceeded by 2010 if the 2+ criteria is used. OCTD plans to begin with a 2+ criteria (currently about 85 percent of share-ride person trips in Orange County are

Table 9–4. Transitway Demand Estimates for Year 2010
(SR 57/I–5/SR 55 Transitway)

Item	High Occupancy Vehicles If 2+	High Occupancy Vehicles If 3+	Transit Services Public and Private
Daily Person Trips	123,600	52,700	22,100
AM Peak Hour Vehicles			
Total on Facilities	11,000	3,000	140 buses
At Maximum Location in One Direction	3,700	1,400	50 buses

Source: Orange County Transit District, "A Transitway Development Program for Orange County," Oct. 1986, p.35.

two-person carpools) as available projection indicate that the numbers of 2+ carpools will not be great enough to degrade carpool or bus speeds for several years.

OCTD expects to change the criteria for carpool use when usage for each transitway segment reaches approximately 1,500 vehicles per lane per hour; this would insure that the transitways continue to provide high-speed and reliable travel. Although OCTD recognizes that many motorists will object to raising the carpool criteria from 2+ to 3+, they hope that an extensive marketing and education campaign designed to encourage more motorists to form 3+ carpools before the official change will avert serious opposition. Once again, Houston's experience is encouraging.

Express bus services using the complete system of transitways and commuter lanes in Orange County are expected to carry approximately 22,000 daily riders in the year 2010. According to OCTD's projection, the highest bus volumes, 50 buses per hour, would occur on the SR 57 segment southbound, between SR 91 and Katella Avenue, during the AM peak hour, and a fleet of 140 buses would be needed in the peak hour. With a 3+ carpool requirement and 50 buses per hour, the segment with this highest projected bus volumes would serve 6,100 southbound transit and carpool trips during the morning peak hour, roughly three times as many as each general freeway lane.

In addition to increasing effective capacity and relieving congestion, the transitways and commuter lanes would also provide travel time savings for users of these facilities. OCTD estimates that travel time savings for the typical commuters in Orange County will range from 10 minutes for a trip from the Tustin area to the airport to 22 minutes for a trip from the Fullerton area to the South Coast Metro area. Carpools are expected to save an average 11 or 12 minutes per trip or about one minute per mile.

Commuters using the proposed transitway would also benefit from less variability in travel times. Transitways would insulate carpools and bus passengers from the accidents and other "nonrecurring" incidents which occur with increasing frequency on Southern California freeways (OCTD, 1986). Transitway volumes can be controlled, through occupancy restrictions and other entry control measures, i.e. ramp metering devices, to insure speeds remain significantly higher than in the main lanes during peak hours. This greater reliability will permit many transitway commuters to leave for work at slightly later times.

Most public transit use of Orange County's transitways will be peak-period commuter trips to and from the major activity centers. About a third of the proposed transitway bus routes are expected to have enough demand to justify 30-minute or less headways. A fleet of approximately 244 buses would be required for these routes by 1995. In most cases, the OCTD transitway routes will consist of express bus services between designated park and ride lots and single activity centers. Some routes will make stops at one or two "intermediate" park and ride lots if they can be reached quickly from the transitway. Some routes, moreover, may serve two activity centers, if the centers can be served without excessive delay. Furthermore, buspool/subscription service will be provided to smaller employment centers and large single firms in the county, including, for example, McDonnell Douglas in Huntington Beach. OCTD estimates that subscription services will require approximately 30 additional buses.

Costs and Implementation

As the data in Table 9-5 indicate, OCTD consultants estimate the 19.4-mile transitway system would cost $472 million or $24.3 million per mile to build (in 1989 dollars).* These costs reflect some cost savings where joint project development with Caltrans is required. The $472 million estimate of total costs includes a 15 percent estimate for handling traffic, 20 percent estimate for engineering and management and a 25 percent estimate for contingencies.

OCTD plans to develop the proposed transitway segments with other Caltrans projects to minimize design conflicts and facilitate construction. For some proposed transitway segments it will be possible to make preferential improvements without committing to the complete transitway project.

Table 9–5. Estimated Cost of Transitway System by Segment (in Millions of 1989 Dollars)

Segment	Limits	Length (miles)	Total Cost Estimate	Cost Per Mile
1	I–5 from SR 22 to 4th Street	3.3	$96.6	$29.3
2	5/55 Interchange	1.8	$60.1	$33.4
3	SR 55 from AT&SF to MacArthur Blvd.	2.6	$70.8	$27.2
4	55/405 Interchange	2.3	$82.6	$35.9
5	Bear and Von Karman ramps on I–405	2.5	$33.3	$13.3
6	I–5 from SR 22 to Katella	2.1	$54.7	$26.1
7	SR 57 from I–5 to SR 91	4.8	$74.0	$15.4
Total		19.4	$472.1	$24.3

Note: Does not include cost for items such as park–and–ride lots, additional buses, or bus maintenance facilities which will be needed to support the projects.

Source: OCTD Report, 1986

* Please note that we have not conducted a detailed analysis of the cost estimates presented here. We have limited ourselves to reporting the figures made available by OCTD.

Orange County's the transitway and commuter lane plan is a comprehensive and sophisticated effort to deal with the area's worsening traffic problems. Orange County's tentative decision to rely exclusively on transitways and commuter lanes to provide its growing population with high-quality transit service is almost unique among American cities.* Its progress or lack of progress in developing its proposed transitway and commuter lane system will by closely watched by urban planners elsewhere in the hope that it will provide some answers to the ever-growing dilemma of congested urban highways.

* It is also controversial as advocates of an Orange County LRT system continue to press to county for building light rail rather than the transitway system proposed by OCTD.

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Chapter 10. Development and Operation of Houston's Transitways

Introduction

Houston's evolving express bus and transitway system is the most ambitious and innovative effort to provide suburban residents with high-performance, high-speed, and cost-effective commuter services implemented by any North American city since World War II. The Board of Directors of the Metropolitan Transit Authority of Harris County (METRO) in Houston has approved the construction of 95 miles of transitways and expects to have completed nearly 90 miles by 1995. Using the revenues from a dedicated one percent sales tax and generous federal capital subsidies, METRO has built these facilities without borrowing, while at the same time aggressively expanding local bus services for central city residents and maintaining low fares.

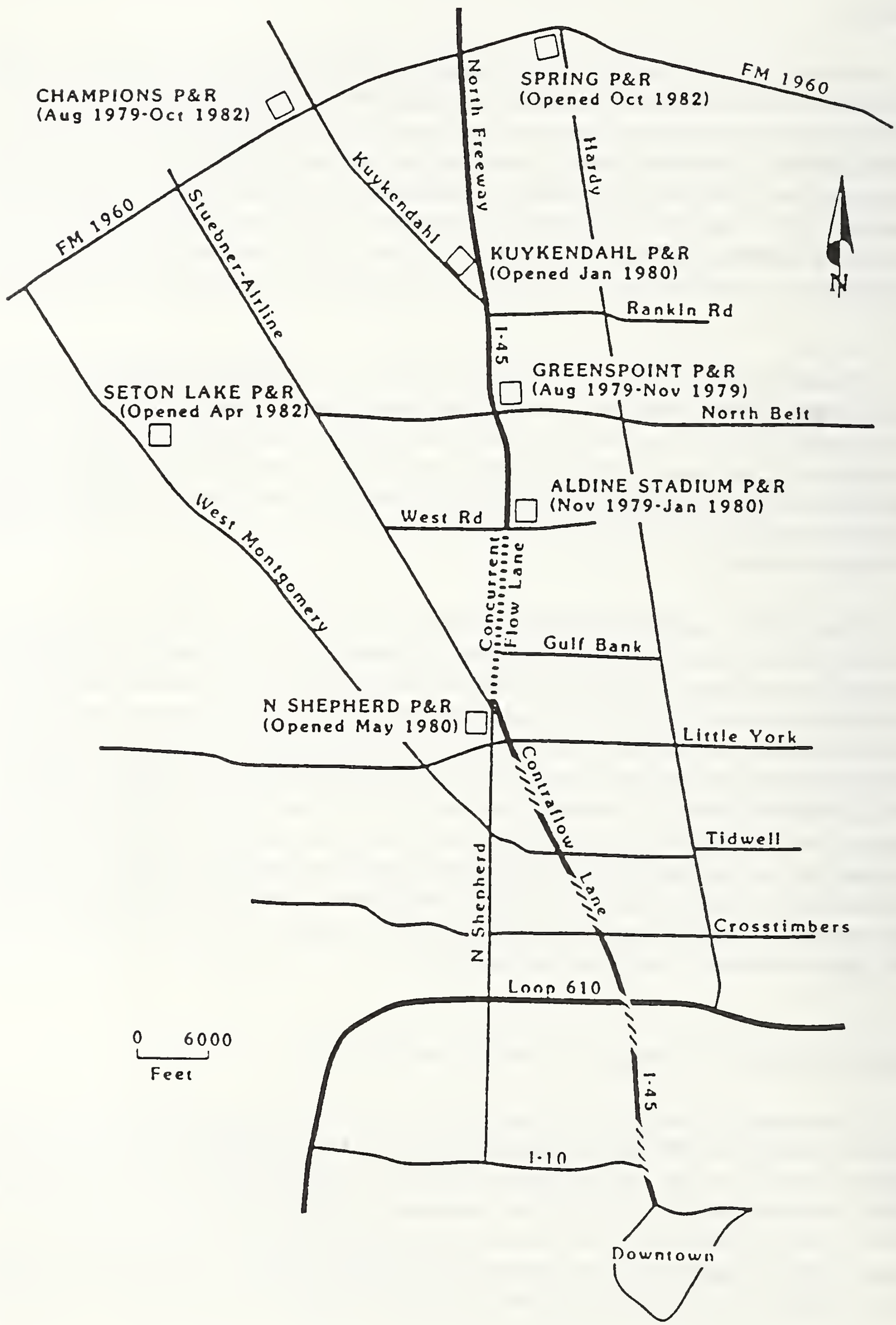
Transitways, as the term is now used in Houston, are physically segregated, reversible, one-lane roadways built mostly in the center of radial expressways. Depending on the extent of transit demand, Houston's transitways may be used by buses, vanpools, and carpools. In the case of the North Transitway, a 19.7 mile facility located in the median of the I-45 North Freeway, only buses and authorized vanpools are permitted to use the facility. The remaining transitways are available to carpools with two (2+) or three or more (3+) persons per vehicle, with eligibility depending on demand.

When METRO opened the Katy Transitway in April 1985, it planned to limit its use to buses and vanpools. At the end of the first year of operations, however, only 386 vehicles a <u>day</u> were using the transitway. Even though the vehicles using the Katy Transitway carried more persons during the peak hour than were served by each of the adjacent general traffic lanes, the facility looked empty. Motorists in the congested adjacent general traffic lanes concluded the seemingly empty facility was badly underutilized and demanded greater access for private cars. METRO, concerned about an upcoming referendum on its long range mobility plan and an threatened initiative petition to cut its dedicated sales tax in half, agreed first to open the lane to "authorized" 4+ carpools and finally, under growing political pressure, to allow <u>all</u> 2+ carpools to use the transitway. Subsequently, with the referendum behind it, METRO returned to a 3+ criterion for the Katy Transitway during the AM peak period, while retaining the 2+ criterion during the PM peak period when carpool demand was less.

Origins of Houston's Transitways: The North Contraflow Lane

The origins of Houston's transitway program are found in a proposal made in 1974, nearly four years before METRO was created, by the Texas State Highways and Transportation Department (SHDT), as the Texas State Department of Highways and Public Transportation (SDHPT) was then known, for a 9.6 mile contraflow bus lane on the North Freeway. This scheme, shown in Figure 10-1, which would eventually cost $3.4 million (1989 dollars), was part of a larger UMTA funded Service and Methods Demonstration (SMD) project that was to provide transit enhancing "corridor improvements" in four of Houston's most heavily used radial

Figure 10-1. The North Freeway Contraflow Lane, Concurrent Flow Lane, and Park and Ride Lots



freeways.* Implementation of the demonstration was delayed, however, and its scope was subsequently drastically reduced. The North Freeway Contraflow Lane (CFL) is the only component of the original SMD proposal that was implemented, although other parts of that proposal have been included in somewhat modified forms in other projects.

In January 1975 Houston's Mayor Hofheinz committed city resources to planning of the contraflow project and SDHPT undertook a feasibility study. Encouraged by the results of this study, the City of Houston Office of Public Transportation (OPT) submitted an application for a SMD grant to UMTA in April 1975 for improvements to four radial freeways at a total cost (all figures are in 1989 dollars) of $2.5 million (1989 dollars) of which $325,000 was for the North Freeway. On June 30, 1975, UMTA agreed to provide $1.8 million as its share of the $2.5 million project cost.

Further analyses by SDHPT reconfirmed the feasibility of a contraflow lane on the North Freeway, but also indicated that the facility would cost substantially more than the initial project estimate. In January 1977 SDHPT notified the city that implementing the North CFL would cost $2.1 million; six months later it raised its estimate to $3.2 million (both of these figures are in 1989 dollars). In June 1977, the city applied to UMTA for Capital Grant Assistance, and in August 1978 UMTA agreed to increase its funding to $2.3 million (1989 dollars), earmarking the entire amount for the North Freeway CFL. The North Freeway CFL was completed in January 1979, the same month that METRO took over transit operations from HouTran, and the North Freeway CFL was finally opened to traffic on August 28, 1979.

On March 30, 1981 METRO buses began using a concurrent flow lane, built by SDHPT, that extended the CFL an additional 3.3 miles during the morning peak. Neither diamond symbols or pylons were used to separate the concurrent flow lane, which was created from the median shoulder, from the left-most mixed traffic lane. Buses and authorized vanpools were permitted to enter or leave the concurrent flow lane at any point. The entire $196,000 cost of the lane (1989 dollars) was paid from local sources.

Table 10-1 provides a summary of the capital costs of North Freeway corridor improvements and the funding sources for each. As these data reveal, the final cost of the North Freeway Contraflow Lane was $3.1 million (1989 dollars), of which UMTA paid 93 percent. In addition to the contraflow lane itself, the project included a number of complementary capital improvements, including ramp metering (paid for by Federal Aid Interstate funds and SDHPT), two park and ride lots, and the previously mentioned concurrent flow lane. The total cost of the North Freeway Corridor improvements was over $10.7 million (1989 dollars), including $3.3 million for the North Shepherd park and ride lot.

The Federal Highway Administration (FHWA) and SDHPT paid 70 percent of the cost of the North Shepherd lot, while METRO paid the entire $3.5 million cost (1989 dollars) of the Kuykendahl park and ride (P&R) lot. METRO paid about one-fourth and SDHPT three-fourths of the construction costs of the concurrent flow lane. Incremental operating costs in 1989 dollars of the contraflow lane during the 18 month demonstration project (management, daily operation,

* Unless otherwise noted, all dollar figures are in 1989 dollars. Construction cost numbers are converted into 1989 dollars using the ENR Construction Cost Index. All other figures are indexed using the GNP Implicit Price Deflator.

Table 10–1. Capital Costs For North Freeway Corridor Improvement (Dollar Figures Are in 1989 Dollars)

	Funding	Costs
Contraflow Lane Construction		$3,095,000
UMTA SMD	$580,000	
UMTA Section 5	$2,287,000	
City of Houston	$85,000	
Texas Public Transportation Fund	$142,000	
Ramp Metering Construction		$563,000
Federal Aid Interstate	$394,000	
SDHPT	$169,000	
North Shepherd Park & Ride Lot		$3,313,000
FAUS (FHWA)	$2,319,000	
SDHPT	$994,000	
Kuykendahl Park & Ride Lot		$3,483,000
METRO	$3,483,000	
Concurrent Flow Lane Costruction		$196,000
SDHPT	$142,000	
METRO	$54,000	
TOTAL ($)		$10,650,000

Source: Atherton and Eder (1982), p.3–4

supervision, and enforcement) were estimated to be $1.1 million, and METRO paid contract bus companies approximately $6.2 million or an average of $17,500 per day.

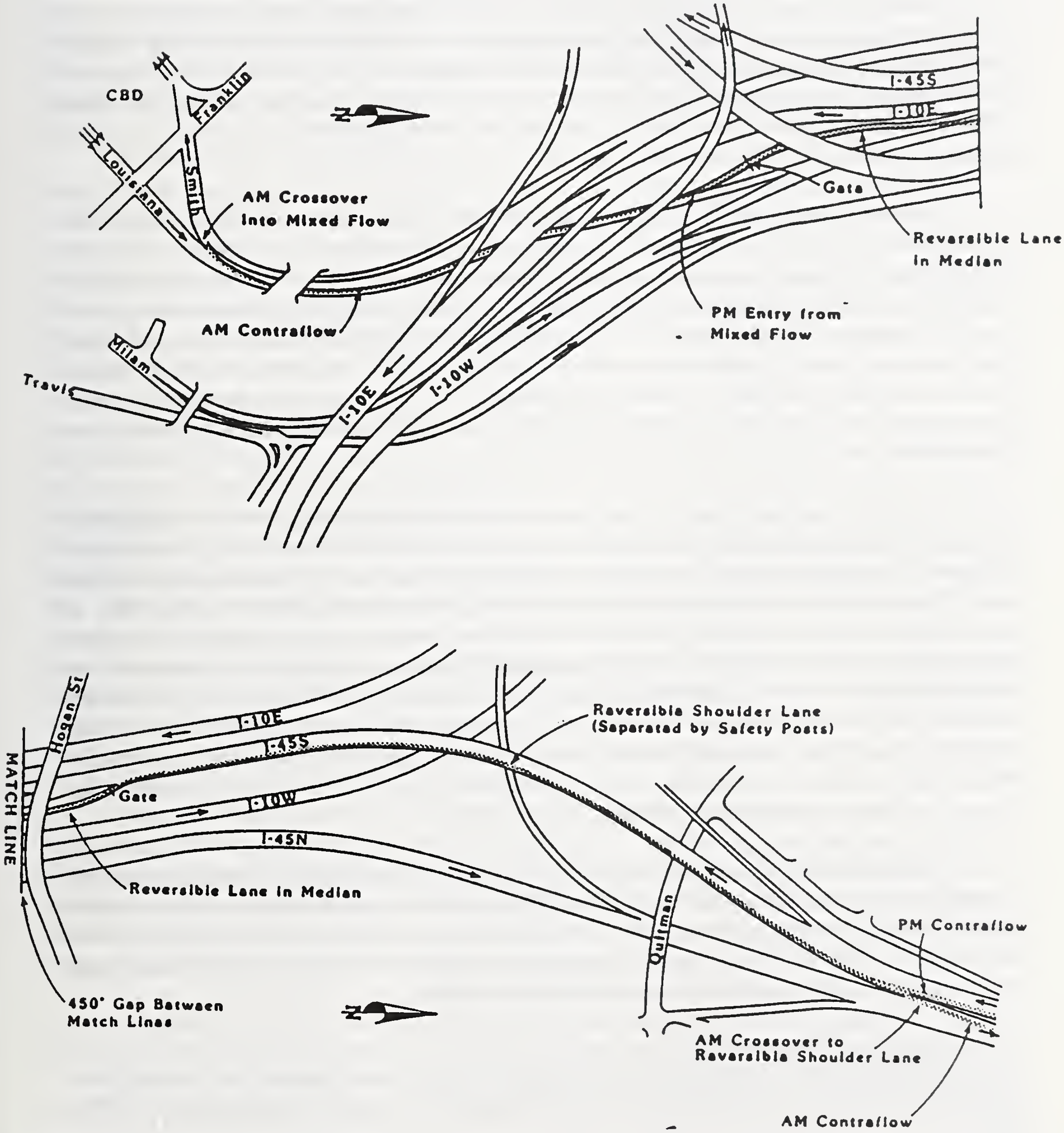
Operation of the North Freeway Contraflow Lane (CFL)

As Figure 10-1 shows, the North Freeway Contraflow Lane extended 9.6 miles from downtown Houston north to North Shepherd, and the AM peak (inbound only) concurrent flow lane extended from that point north to West Road (Kuo, 1987, p. 20). During the AM peak period, buses and authorized vanpools were allowed to enter the CFL from either the concurrent flow freeway lane or from a button-hook ramp at Stuebner-Airline Road. Buses operating from the Shepherd park and ride, for example, used the ramp at Stuebner-Airline Road to reach the CFL. The button-hook ramp at Stuebner-Airline Road was also used to exit the CFL in the afternoon. Since the concurrent flow lane did not operate during the afternoon, buses and vanpools with destinations beyond the end of the CFL had to cross the median and merge with the general traffic using the outbound freeway lanes.

The southern (downtown) terminus of the CFL was connected directly to the downtown streets. The CFL's connections to downtown are depicted in Figure 10-2, where the upper panel shows the segment that connects to downtown and the lower one shows the outer segment. In the morning, CFL vehicles crossed the median to a reversible flow lane located on the

Figure 10-2.

North Contraflow Lane Connections to Downtown



inside shoulder of the southbound (inbound) freeway. This reversible shoulder lane was then connected to an exclusive, barrier separated reversible median lane which merged with still another contraflow segment located on an outbound ramp from the downtown street network. During the PM peak, the operation of these facilities was reversed and outbound CFL vehicles accessed the facility directly from the outbound general traffic freeway lanes.

During the first year speeds on the CFL were limited to 45 mph. Subsequently, the speed limit was raised to 55 mph and METRO imposed a 3 second rule for spacing between authorized vehicles. A speed check just prior to the speed limit change revealed that most contraflow vehicles were traveling at speeds between 45 and 55 mph. A second speed check made in October 1980, after the rule change, indicated the average speeds were 57 mph for buses and 54 mph for vans.

Concerns about safety, and particularly worries about head-on collisions, are a common source of opposition to contraflow bus lane schemes. However, the accident experience with the North Contraflow Lane is reassuring. During the first 18 months of operation and 1.7 million miles of contraflow lane travel there were only 4 accidents (2.4 per million vehicle miles) involving vehicles in the contraflow lane.* As a result of reduced congestion in the peak direction, moreover, peak period accident rates in the North Freeway mainlanes actually decreased from 2.4 accidents per million vehicle miles during the six month period preceding the implementation of the contraflow lane to 2.1 accidents in the six month period following (Atherton and Eder, 1982, p. 5-20).

Atherton and Eder (1982, p. ES-6), in a December 1982 evaluation for UMTA, judged the CFL project "highly successful," and found that "use of the contraflow lane during the peak hour resulted in an average round trip travel time savings of 40-minutes for bus riders and vanpoolers." The estimated travel time savings referred to by Atherton and Eder are presumably an upper bound since they make no allowance for increases in trip lengths that might be required to use the CFL. They were computed by comparing the average speed for the entire 9.6 mile facility after its implementation (24 mph during the morning peak and 16 mph during the evening peak) with speeds on the contraflow lane, which averaged 55 mph during both morning and evening peaks. These speed differentials over the 9.6 mile segment translate into average savings of 14.5 minutes in the morning and 25.5 minutes in the afternoon. A more qualitative, but no less valid assessment was provided by Berryhill (1984).**

The Atherton-Eder report also found that the North CFL improved conditions for non-priority lane users during the peak hour in the initial months of contraflow operation, as a result of shifts of buses and vanpools to the contraflow lane and mode shifts by some motorists to buses and vanpools. The 12 minute round trip savings for motorists using the non-priority lanes, however, eventually disappeared as use of these lanes increased.

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* These four accidents, however, resulted in two fatalities and a number of serious injuries. In the first of two contraflow related fatalities, an auto skidded out of control into the contraflow lane where it was hit by a van. The auto driver was killed instantly and the van driver suffered broken bones. In the other fatality, a CFL bus hit a pedestrian who was attempting to cross the freeway.

** In a discussion of the relative speeds, performance, and attractiveness of bus rapid transit and heavy rail Berryhill asks the following rhetorical question. "Ask the bus passengers in far north Houston who voted against the heavy rail proposal. They were outraged that the METRO plan called for transferring them off their high-speed contraflow buses and into a train" (Berryhill, 1984, p. 3B).

At the same time the contraflow lane was opened, METRO introduced several new express bus routes. Prior to contraflow operations there were no park and ride facilities serving the corridor and transit services were limited to two private commuter routes operated by Oliver Bus Lines which provided about seven bus trips per peak period on the North Freeway.* By May 1980, METRO was operating five bus routes (with services contracted from private operators) and three park and ride lots (two permanent and one temporary). Two years later, the average number of bus trips using the North CFL during the peak period had increased to 103 (Atherton and Eder, 1982, p. 6-8). METRO's Annual Report, 1981 (p. 7) claimed that the North Freeway CFL and concurrent flow lanes provided time savings of 33 minutes a day for approximately 7,500 people.

In Fiscal Year 1980 METRO opened its first two permanent park and ride lots at Kuykendahl Road near I-45 and at the intersection of North Shepherd and Stuebner-Airline (Figure 10-1). The 13 acre Kuykendahl park and ride lot provided parking for 1,200 cars and cost $3.5 million (1989 dollars). The North Shepherd park and ride lot, with spaces for 750 cars, was built by SDHPT in conjunction with the North Freeway Contraflow Lane project. METRO also signed a three year agreement for a 250 car park and ride lot leased from the Texas Commerce Bank-Katy for $1 a year (nominal dollars). During 1981-82 METRO continued to aggressively expand its park and ride lots and by the end of Fiscal Year 1982 it was operating 17 lots.

In combination, the CFL time savings, park and ride lots, and new express bus services had a dramatic impact on bus use. During the first 33 months of CFL operation, AM peak period bus ridership on the North Freeway increased by 16 fold (Atherton and Eder, 1982, p. 6-9). Immediately before the CFL began operating, AM peak period transit ridership in the corridor totaled 265 persons, after 33 months it had grown to 4,500. At the end of its first year of operation, the North Freeway CFL was already carrying an average of 8,724 persons daily in 537 vehicles. The facility reached its peak utilization rate in September 1983 when it served a combined total of 16,500 passengers a day in vanpools and buses (Kuo, 1987, p. 1). Oil shock induced declines in metropolitan, and, particularly CBD, employment and construction on the North Freeway combined to decrease usage, and particularly vanpool use of the CFL. As we discuss at a later point in this chapter, ridership once again began to increase after the completion of the North Freeway Transitway AVL (Authorized Vehicle Lane).

Vanpool ridership exhibited a pattern similar to the one described above for bus ridership, except that it began to decline slowly in June 1982. Large employment declines, particularly the large loses in CBD employment, directly impacted bus and vanpool ridership, as many users lost their jobs, and indirectly affected ridership as employment declines and reduced peak period travel led to improvements in speeds and travel conditions on the adjacent general traffic lanes.

Violations of the CFL ridership restrictions were quite low. Since only buses and vanpools were allowed to use the lane, the detection of violators in the CFL was much easier than it

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* When the CFL was being planned, analysts thought that the HouTran routes using the North Freeway between Cross Timbers and downtown (see Figure 10-1) would be able to use the facility. These routes, with 25 buses and approximately 625 passengers per day, were never able to use the CFL, however, because a planned contraflow entrance/exit at the 610 interchange, the midpoint of the CFL, was never built. (Atherton and Eder, 1982, p. 6-5).

would have been for concurrent lanes that permit carpools. After the first year of operation, violations averaged only seven per day.

When the 3.3 mile concurrent flow lane extension of the CFL was first opened on March 30, 1981, it was used by about 260 vehicles (75 buses and 185 vanpools); after one year of operation this number had increased to 335 vehicles (Atherton and Eder, 1982, p. 4-29). Before the concurrent flow lane was available, approximately 78 percent of all vanpools entered the CFL from the I-45 mainlanes, as opposed to the North Shepherd access ramp. Within one month of the opening of the concurrent flow lane, 95 percent of vanpools were entering the CFL from the concurrent flow lane (Kuo, 1987, p. 23). When the concurrent flow lane was discontinued in November 1984, about 90 percent of vanpools and 85 percent of buses were using it to reach the contraflow lane in the morning (Ibid, p. 23).

The Development of Houston's Transitways

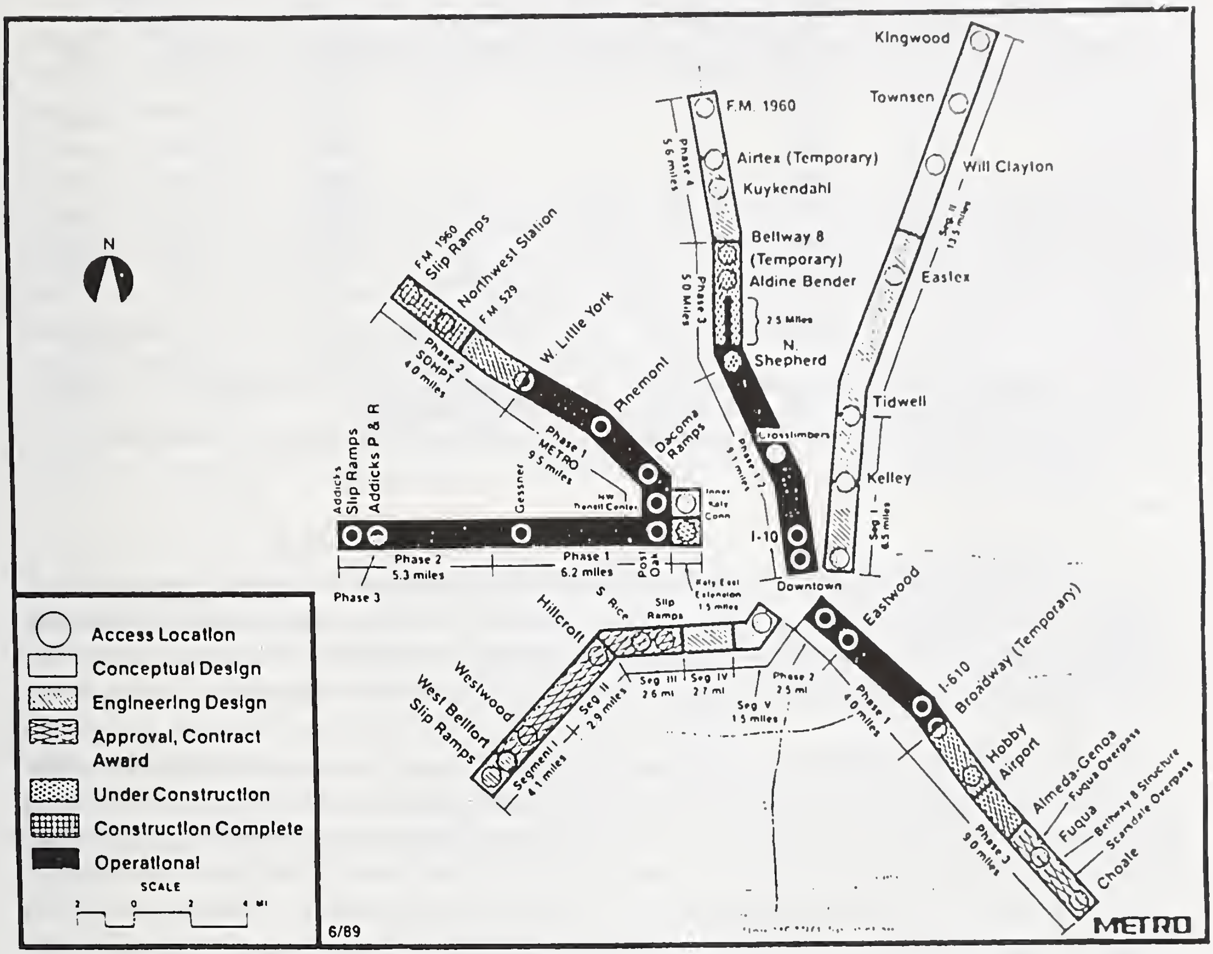
When it is finally completed in 1995, Houston's transitway system will consist of the six radial facilities shown in Figure 10-3. As of April 1989, 36.6 miles of transitway in four corridors were fully or partially operational, and an additional 58.9 miles were in various stages of design, planning or construction. The dynamic nature of Houston's transitway program makes it difficult for analyses of it to keep up. For example, the November 1988 "Transitway Utilization Report" does not even mention the Eastex Transitway. METRO included the Eastex Transitway in its program in November-December 1988 in a decision that was prompted by an SDHPT decision to accelerate reconstruction of the Eastex Freeway. In this and many other instances, METRO responded to a SDHPT decision process that forced METRO to commit itself to a project, perhaps earlier than it would have preferred. If METRO had waited, the opportunity to build a low cost transitway in the corridor would very likely have been lost for years, if not decades.

Table 10-2 provides a status report on Houston's transitway program showing the mileage in operation, under construction, under engineering design, under conceptual development and proposed for each of the six transitways, as well as the capacity of the complementary park and ride lots, the estimated completion dates, current ridership (all modes), and current and projected Year 2000 ridership (all modes). The projected Year 2000 patronage estimates were prepared before July 1987 and do not reflect METRO's current policies on carpool use of the transitways. It is likely that the "All Modes" forecast for Year 2000 includes only buses and vanpools. At the same time, METRO's Year 2000 projections of daily transit ridership have been dropping steadily, from 450,000-500,000 in 1980 to 240,000-280,000 in 1988, largely reflecting slower growth caused by declining oil prices. Forecasts prepared for METRO's 1989 "Rail Research Study" using the METRO-UTPS model were in the 250,000-300,000 range (TTI, 1989c). Ridership forecasts by Charles River Associates analysts were somewhat lower, particularly for rail alternatives, and analyses by Kain (1989) suggest even these forecasts may be too high.

Houston's First Transitway: The North Freeway AVL

The North Freeway Contraflow Lane was considered an interim solution from the beginning, as traffic in the off-peak direction was expected to grow rapidly to a level where the taking

Figure 10-3. Status of Houston's Transitways (June 1989)



Source: METRO (1987c, 1989b).

away of an off-peak direction general purpose freeway lane could no longer be justified. When SHTD first suggested the idea of exploiting the North Freeway's favorable directional split in 1974, about 75 percent of AM trips on the North Freeway were in the peak direction and the PM split was 69 percent. By the time the contraflow lane was finally opened in August 1979, these directional splits had decreased to 69 percent in the morning and 61 percent in the afternoon. Studies by SDHPT concluded that by "1985, if not sooner, off-peak direction traffic would have increased sufficiently to warrant the discontinuation of the Contraflow Lane" (Kuo, 1987, p. 26).

Recognizing the success of the CFL and responding to SDHPT's warnings that the contraflow lane would soon have to be restored to use as a general traffic lane, METRO's board on October 28, 1981 approved spending approximately $5.4 million (1989 dollars) in local funds for detailed studies and design of an Authorized Vehicle Lane (AVL) to replace the North Freeway CFL. The term "Authorized Vehicle Lane" refers to METRO's policy that only authorized vehicles could use the lane, and before its completion the North CFL. Authorized vehicles had to have: 1) certified drivers familiar with the transitways geometry; 2) valid Texas inspection stickers no more

Table 10–2. Status of Houston's Transitway Program (December 1988)

Transitway	Total Mile	Comp. Date (Est.)	In Oper. (miles)	Under Const. (miles)	In Design (miles)	P&R ** Capacity	Passenger/Day All Modes 1988	2000
North (I–45)	19.7	1993	9.1	5.0	5.6	6,721	12,964	35,000
Katy (I–10)	13.0	1989	11.5	1.5		4,058	16,772	22,000
Gulf (I–45)	15.5	1990	6.5	9.0		5,377	5,369	21,000
Northwest (US 290)	13.5	1990	9.5	4.0		3,422	1,844	25,000
Southwest (US 59)	13.8	1991			13.8	3,715	NA	31,000
Eastex	20.0	1995			20.0	NA	NA	NA
Total	95.5	1995	36.6	13.9	39.4	23,293	NA	134,000

**: Capacity of existing and planned P&R lots through which buses will use transitway.

Note: Under Const. includes under construction; completed, but not operational; and approved and contract award.
In Design includes engineering design and conceptual design.

Source: METRO (1989b).

than six months old; 3) the minimum state insurance coverage; and 4) passed a visual vehicle inspection by METRO. In the case of the North Freeway, authorized vehicles were limited to buses and vanpools. As we discuss in more detail later in the chapter, authorization was initially required for vehicles using the Katy Transitway, but was subsequently dropped.

The success of the North Transitway, or, perhaps more accurately, the success of its predecessor, the North CFL, paved the way for the development of similar facilities in the region's remaining freeway corridors. Construction of the North Transitway is being carried out in four phases as part of a broader North Freeway Improvement Project. The SDHPT was able to reconstruct the North Freeway and build the North Transitway without interrupting METRO operations. It did close the concurrent flow lane during construction, however, and METRO had to operate during much of the reconstruction period under less than ideal circumstances.

During Phase I (completed November, 1984), the North Freeway CFL from downtown Houston to North Shepherd Drive was replaced with a temporary narrow (16-foot) barrier-separated reversible median HOV lane. Phase II (completed May 1987) entailed widening the same freeway segment to provide additional freeway lanes, a number of other general freeway improvements, and widening of the North Freeway AVL to its final width of approximately 20 feet. Phase III (completed October 1988) extended the North Transitway an additional 4.5 miles to North Belt (Beltway 8). Completion of Phase III provided a replacement for the concurrent flow lane, lengthened the facility 1 mile beyond the former terminus of the concurrent flow lane, and provided for both AM and PM peak period operations. Phase IV is projected for completion in two segments. The section Beltway 8 to Airtex is to be operational in 1994 and the final section, from Airtex to FM 1960, is to be operational in 1997. When it is completed, Phase IV will extend the North Transitway another 5.6 miles to FM 1960, resulting in a 19.7 mile barrier separated roadway from downtown Houston to FM 1960. The locations of the three transitway segments constructed during the project's four phases are shown in Figure 10-3.

The most serious operational problems during Phase I construction occurred when vehicles broke down and had to be towed from the temporary AVL, which was too narrow to

permit passing of a disabled bus. An average of four vehicles a month had to be towed from the temporary AVL during its first year of operation. While no data on actual time lost are available, Kuo (1987, p. 77) reports that removing a disabled vehicle from the transitway took up to 30 minutes, including the time required to detect, respond, and remove the disabled vehicle. This translates into an average 15 minutes of delay per vehicle for each vehicle entering the Transitway upstream of the incident.

Construction activities, of course, also adversely affected travel conditions in the freeway mainlanes. Counts completed by TTI indicated that the number of passengers using the North Freeway CFL-Temporary AVL during peak periods decreased from an average of 7,216 during the period just before construction began (June-November 1983), to 6,105 per day during the construction period (February-September 1984), and to 6,697 while the Temporary AVL was operating (December 1984 - September 1985). During these same periods, the average number of persons carried by the freeway mainlanes fell from 14,547, to 13,272, to 12,840 (Kuo, 1987, p. 85-86). These changes, of course, reflect employment declines and other factors as well as the impact of construction induced delays.

During November 1988, an average of 304 buses and 253 vanpools used the North Transitway AVL each day, carrying 10,700 bus riders and 2,248 vanpoolers (METRO, 1988). A benefit/cost analysis conducted by TTI after the Temporary AVL's first full year of operations found that commuters using the AVL saved an average of 9 minutes a trip (the average of the morning and afternoon average peak period travel time savings).* Since an average of 14,542 persons a day were using the AVL at that time, this translates into savings of 2,181 person hours a day. Valuing each person-hour of delay at $8.13 (1989 dollars), TTI analysts found that the facility produced an annual non-discounted benefit of approximately $4.62 million (1989 dollars) during its first year of operation (Kuo, 1987, p.89).

Discounting the estimates of these annual benefits over 20 years at 10 percent (all figures are in 1989 dollars), the TTI analysts obtained $39.4 million in travel time savings over the 20 year life of the facility. In addition, TTI analysts found bus operating cost savings for the same period would total $6.4 million, for an estimate of total discounted benefits of $45.8 million. Comparing these estimated benefits to an estimated $16.5 million in capital and operating costs for the facility produces a benefit/cost ratio of nearly three (Kuo, 1987). TTI's benefit estimates, moreover, are obviously quite conservative as neither the time savings per trip or utilization of the AVL are assumed to increase over the life of the project and a fairly high annual discount rate, 10 percent, is used in discounting future benefits.

The Katy Transitway

METRO's 1978 Regional Transit Plan (p. 24) called for a number of "transit enhancing" improvements for the Katy Freeway (I-10 West) and its frontage roads during 1980. These improvements include "bus priority signalization, intersection redesign and widening of a small segment of the roadway for improved flow." The plan also allocated an estimated $233 million

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* TTI analysts argue that the 9 minute estimate is very conservative since most the transitway trips are made in the peak hour as opposed to being spread out uniformly across the entire peak period.

(1989 dollars) for the construction of "exclusive transitway facilities by the Metropolitan Transit Authority" in the Katy corridor. METRO opened the first phase of the Katy Transitway in 1981, only a year later than was projected in the 1978 plan.*

Located in the median of the Katy Freeway in the West Houston area, the transitway ends just inside the 610 Loop, six miles from the central business district (CBD) (See Figure 10-3). METRO analysts contend that the fact that the facility does not continue all the way to the CBD is not a serious problem since there is very little congestion inside the 610 loop. The 13 mile Katy Transitway, including the 1.5 mile, $6.1 million (1989 dollar) Katy Transitway Eastern Extension, has been developed at a total cost of approximately $50.4 million (1989 dollars), or $3.9 million per mile. Of this amount approximately six percent was funded by UMTA Section 3 or Section 5 monies, 85 percent was funded by METRO, and nine percent was funded by SDHPT.

The design of the Katy Transitway, a one-lane, reversible HOV facility is almost identical to the North Transitway. Like the North Freeway AVL, the 13 mile Katy Transitway had a phased completion schedule. As Figure 10-3 indicates, Phase I was a 6.2 mile segment from Post Oak to West Belt, including an elevated ramp at Post Oak. It became operational in October 1984 and was completed in August 1985 (METRO, 1989a, p. 7). Phase II, a 5.3 mile segment from West Belt to State Highway 6, was completed in June 1987. The east extension through the I-610/I-10 interchange was completed in October 1989.

The Katy Transitway is 19' 6" wide and consists of one 12 foot HOV lane and a 3'9" shoulder on either side. It is separated from the freeway by concrete barriers and has three access/egress points. Figure 10-4, which depicts cross-sections for the Katy both before and after the construction of the transitway, illustrates how METRO and SDHPT engineers "shoe-horned" the facility into the existing freeway right-of-way. Figure 10-5 shows both the Katy Transitway Eastern Extension, which enables transitway users to bypass the congested West Loop (I-610) interchange and rejoin I-10 on the opposite side where there is little or no congestion, and the elevated ramp which leaves the freeway median (transitway) and connects to the surface streets at the Post Oak and Old Katy Road intersection. At this point, vehicles leaving the transitway can either travel south on local streets toward the Galleria/Post Oak area (a major activity center) or they can continue east to rejoin the Katy Freeway, where they use the general purpose freeway traffic lanes to reach downtown. METRO is also planning an inner connector ramp, which will link the transitway directly to the recently completed Northwest Transit Center.

At the intermediate access/egress location in the vicinity of Bunker Hill, concrete median barrier sections form slip ramps to provide access/egress to the transitway from the inside freeway lanes. Katy's western terminus is reached by the first of several elevated transitway interchanges that are planned for Houston's transitway system. At this point the transitway becomes an elevated structure in the median of the freeway and users of the transitway can either use an elevated T-ramp to reach the Addicks park and ride lot or use a slip ramp to enter or leave the Katy Freeway inside general purpose freeway lanes. Figure 10-6, which shows two photographs of this T-ramp, illustrates this construction. The T-ramp, completed in June 1987, is

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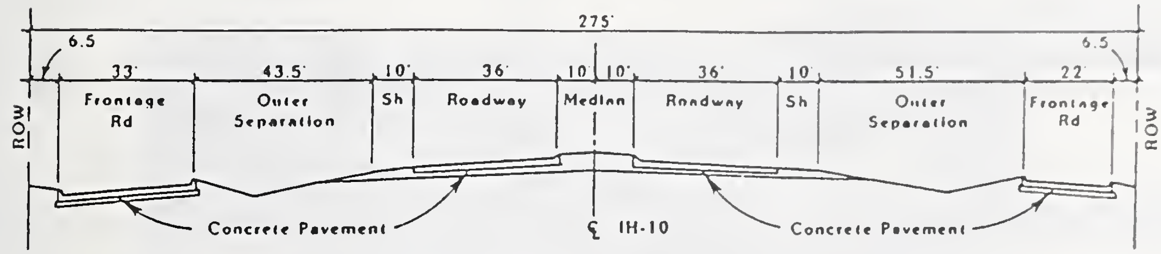
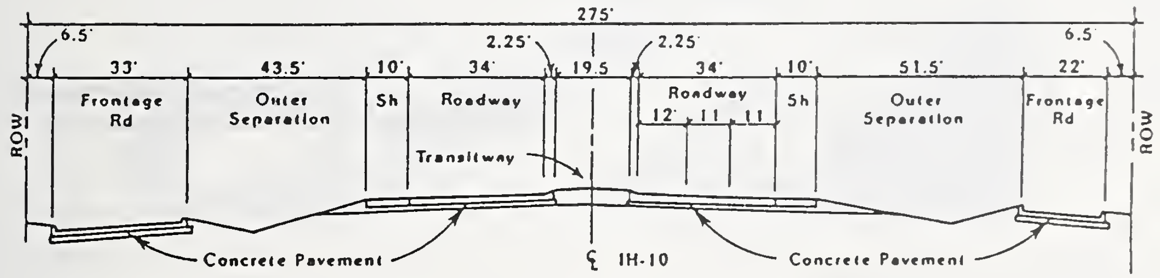
* While precise documentation of METRO's decisions to proceed with the Katy Transitway is beyond the scope of this study, METRO's Annual Report, 1981 mentions discussions with SDHPT on the feasibility of building permanent transitways on I-45 North and the Katy Freeway (I-10 West).

Figure 10-4. Cross-Sections for the Katy Freeway Before and After Transitway Construction



Typical Section Before Transitway Construction



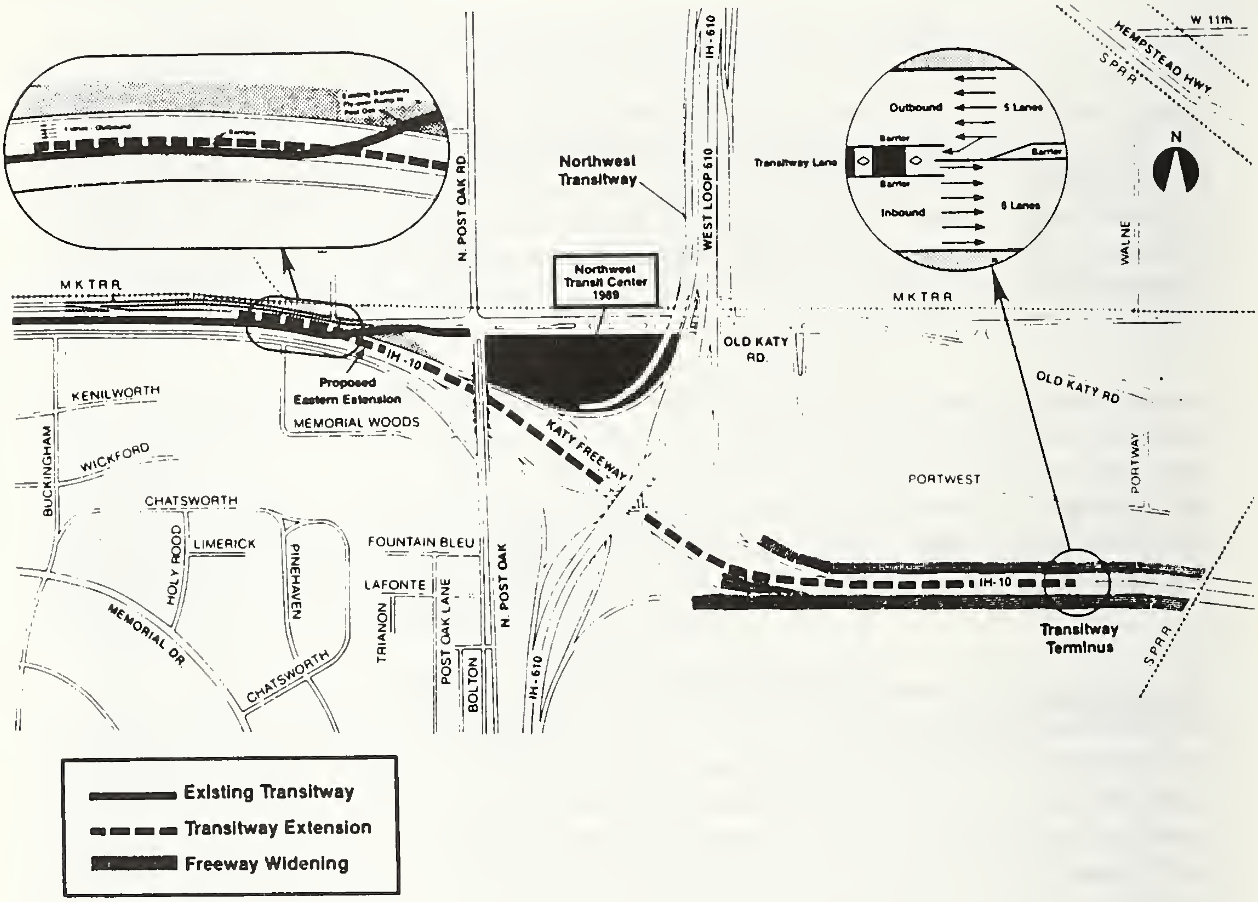
Typical Section After Transitway Construction

designed so that it can be connected to the south side of the freeway at some future time, when it would become a 4-way interchange, permitting authorized vehicles to reach the transitway from either side of the expressway.

At the eastern terminus of the Katy Transitway, all transitway users must pass through a signalized intersection at Old Katy Road and North Post Oak. Vehicles continuing towards downtown must use a section of surface arterial street and reenter the Katy Freeway mainlanes east of the I-610 interchange. When the Katy Transitway Eastern Extension is completed, vehicles headed for downtown will be able to save an additional two minutes over the situation as it now exists (TTI, 1987, p.11).

One of the most interesting and instructive aspects of the Katy Transitway is the evolution of METRO's policies on carpools. As Table 10-3 indicates, when METRO opened the first 4.7 mile segments of the Katy Transitway on October 29, 1984, it permitted, as on the North Freeway CFL and AVL, only buses and "authorized" vanpools to the use the Katy Transitway. After six months of operation only 101 buses and 170 vanpools, carrying 5,046 passengers, were using the facility each weekday. Even though buses and vanpools on the single AVL lane were carrying 16 percent of the combined peak period users of the Katy Transitway and Free

Figure 10-5. The Katy Transitway Eastern Extension



Source: METRO (1989a, Figure 4).

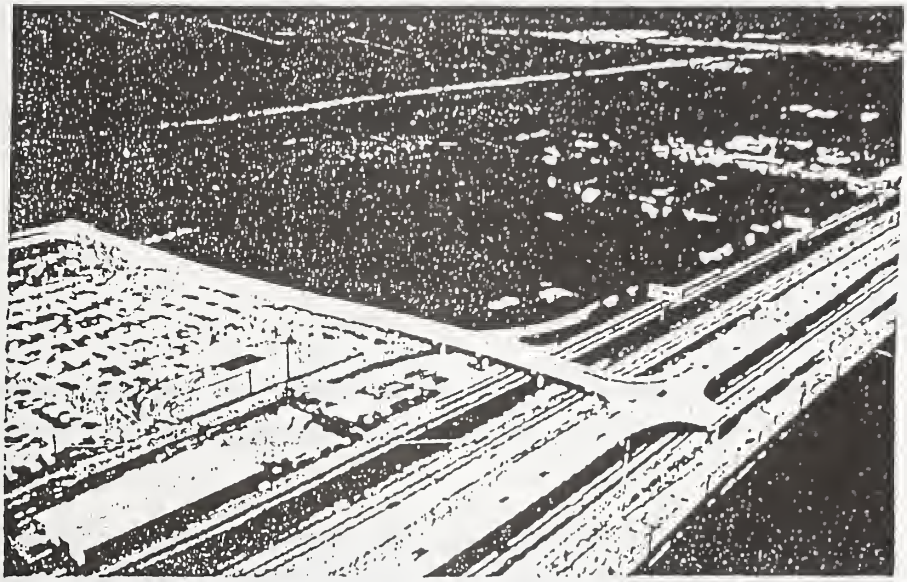
way, motorists in the congested, adjacent freeway lanes perceived the transitway as being grossly underutilized.*

In an effort to overcome the perception that the Katy AVL lane was underutilized (and following the example of both the El Monte and Shirley busways), METRO and SDHPT began a carpool experiment in April 1, 1985. At first, use of the Katy Transitway was limited to authorized vehicles carrying four or more persons. If an authorized vehicle had fewer than four persons it was not permitted to use the transitway. Even so, there were fears that the carpools would adversely affect transit operations.

* While the AVL is striped as a single lane, it is nearly 20 feet wide. This width is required so buses using the AVL can pass a disabled bus. Thus, a more appropriate comparison might be the sum of average volumes in a peak and off-peak direction lane or possibly the sum of an average peak direction lane and the marginal off-peak direction lane. Estimation of the number of vehicles/persons carried in the marginal lane, of course, would depend on the level of service (speed) assumed and the characteristics of the road in question. Because the AVL is barrier separated, disabled vehicles can only be removed at a limited number of access/egress points. At the same time, the fact that access to the AVL can be controlled, means accidents can be cleared quickly.

Figure 10-6.

Elevated T-Ramp Interchange
(Western End of the Katy Transitway)



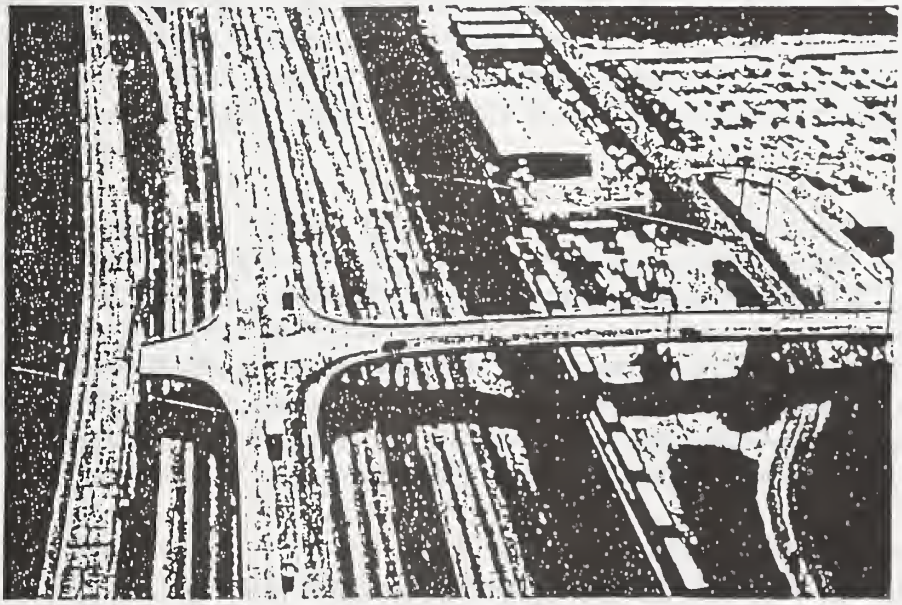


Table 10–3. Chronology of Use Restrictions for Katy Transitway

Oct 29, 1984	Transitway opened from Post Oak to Gessner Drive (4.7 miles); Buses and authorized vanpools.
Apr. 1, 1985	Buses, authorized vanpools, and 4+ carpools.
May 2, 1985	Transitway extended to West Belt Drive (total length 6.4 miles).
July 29, 1985	Buses, authorized vanpools, and authorized 4+ carpools with 3 passengers.
Sep., 1985	Buses, authorized vanpools, and some authorized 3+ carpools.
Nov. 4, 1985	Buses, authorized vanpools, and authorized 3+ carpools.
Aug. 11, 1986	All vehicles with 2+ persons except large trucks and motorcycles.
June 29, 1987	Transitway extended to SH–6 (total length, 11.5 miles).
Oct., 1988	AM peak buses, vanpools and 3+ person carpools; PM peak buses, vanpools and 2+ person carpools.

Source: TTI (1987).

Fears of METRO and SDHPT officials that unacceptable numbers of carpools would use the Katy proved to be unfounded. Only six 4+ carpools used the transitway during a typical morning peak period.* The minimum required number of occupants was lowered as METRO and SDHPT first informally allowed some 3+ carpools to use the transitway and finally, in November 1985, announced the authorization of 3+ carpools. Even with the 3+ criteria, during December 1985 carpool use averaged only 92 trips in the morning and 83 in the evening. Public perception that the Katy Transitway was seriously underutilized continued, and in the face of steadily increasing pressure, METRO and SDHPT opened the Katy to all 2+ carpools on August 11, 1986.

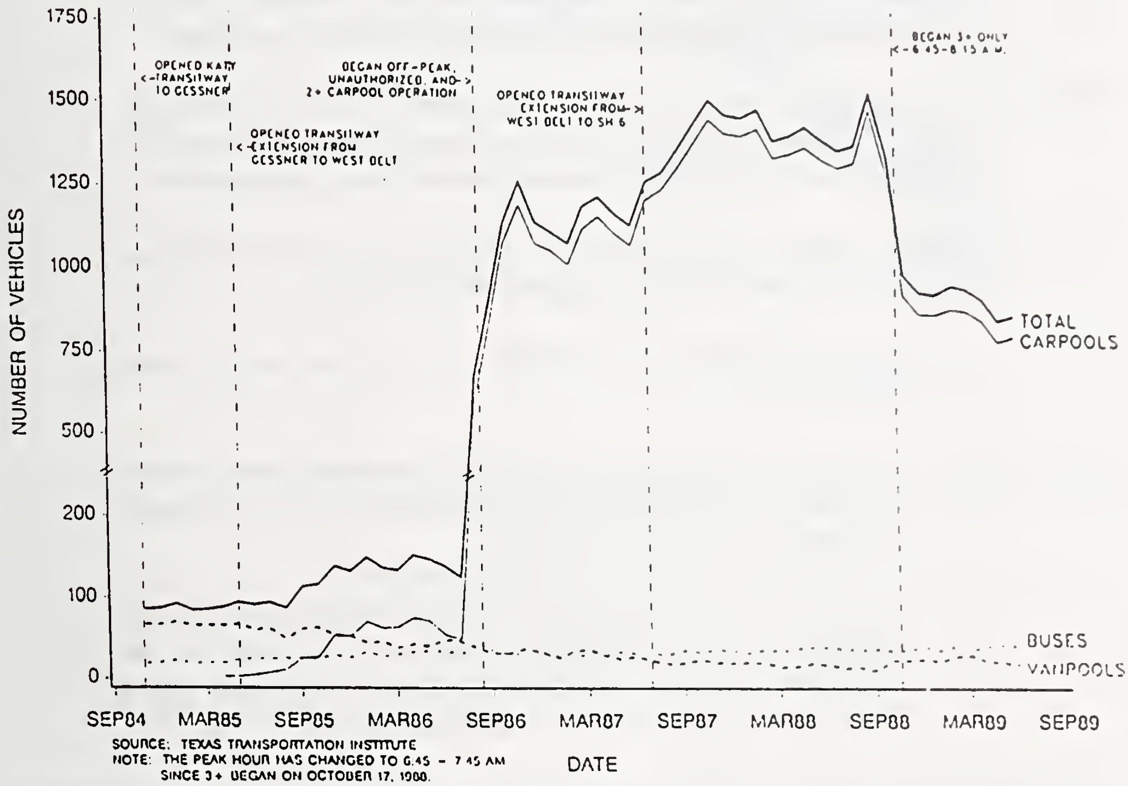
As Figure 10-7 illustrates, the result of opening the Katy Transitway to 2+ person carpools was to dramatically increase the number of vehicles using the facility during the morning peak hour. In May 1986, three months before the Katy Transitway was opened to 2+ person carpools, only 148 vehicles, 35 buses, 41 vanpools, and 72 carpools (3+), used the facility during the AM peak period (Christiansen and McCasland, 1986, p. 9). By September 1987, the month after the transitway was opened to 2+ carpools, vehicle use during the A.M. peak hour had risen to approximately 1,450 vehicles per hour (vph), a level which reduced average transitway speeds from 55 mph to 45 mph or below (TTI, 1987, p. v).

Managing Traffic Volumes and Speeds on the Katy Transitway

At the time METRO agreed to open the Katy Transitway to 2+ carpools it was in the middle of a public relations campaign to persuade voters to approve its Phase II Mobility Plan for

* Kuo and Mounce (1986, p. 20) report that, "The concern that a 3+ designation could possibly exceed the capacity of the transitway and create unacceptable operating conditions also contributed to the decision to initially restrict authorization to 4+ carpools."

Figure 10-7. Number of Vehicles Using the Katy Transitway During the AM Peak Hour



Source: TTI (1989a).

the period 1988-2000. Furthermore, METRO was nervously looking over its shoulder at efforts by several community organizations to obtain signatures for an initiative petition that would have reduced its dedicated sales tax from one to one-half of one percent. Allowing 2+ carpools on the Katy was seen by METRO as a way of blunting the criticisms that the transitways were underutilized and of building support for METRO's plans among carpoolers and other freeway users, many of whom would vote in the upcoming election.

The considerations outlined above slowed METRO's response to the fairly serious AM peak hour congestion and deterioration in express services that were caused by opening the facility to all 2+ carpools. METRO and SDHPT, however, asked TTI to study the problem and to make recommendations. In a September 1987 report, TTI analysts found that AM peak hour volumes were averaging approximately 1,450 vehicles per hour (vph) and that as a result the facility was operating at a level of service in the C to D range. TTI (1987) made the following recommendations to SDHPT and METRO:

1. Expedite the completion of the Katy Transitway Eastern Extension through I-610.

2. Develop and implement procedures for incident management....

3. Undertake an experiment to determine whether overhead cameras could be effectively used to enforce transitway operating regulations.

4. If AM peak-hour volumes begin to approach 1,450 to 1,500 vph, undertake a second mail-out (a first mail-out was sent in September) to transitway users encouraging a voluntary spreading of the peak-hour.

5. If demand begins to exceed 1,500 to 1,600 vph, more stringent demand management strategies will be required. These include:

   A. Reject the alternative of requiring 3+ carpool occupancy during the peak hour.

   B. At this time, develop procedures for implementing authorization for peak-hour transit users. This may be the preferred approach for 'routine' demand management.

   C. At this time, develop procedures for metering and/or closing ramps to control transitway volumes. This may be an acceptable approach for 'routine' demand management and is definitely needed for incidence management (TTI, 1987, p. v.)

TTI's analysis and recommendations relied heavily on an analysis of speed volume relationships for the Katy Transitway. Figure 10-8, which is reproduced from the 1987 TTI report, shows this crucial relationship. In discussing the transitway's capacity, the TTI analysts observe, "once volumes exceed 1,200 vph, average speeds on the transitway between Gessner and Post Oak will be less than 55 mph" and that "an hourly volume of 1,500 vph appears representative of 'capacity' conditions for the Katy Transitway" (TTI, 1987, p. vii). As the dashed lines in Figure 10-7 (added by the authors of this report) make clear, TTI analysts were implicitly recommending that METRO should operate the Katy Transitway in the range 35 - 45 mph rather than at its design speed of 55 mph.* The "Options" paper, unlike most TTI reports, does not identify its author or authors and is instead presented as a "TTI" report. It is unclear whether these recommendations are TTI's "independent" assessment, or whether they reflect the policy preferences of METRO and SDHPT. In this regard, it is worth noting that the TTI recommendation corresponds to a policy to operate the transitway at speeds that maximize vehicular capacity, a position that would be favored by most highway engineers, rather than at speeds that would maximize person capacity, at least in the long run.

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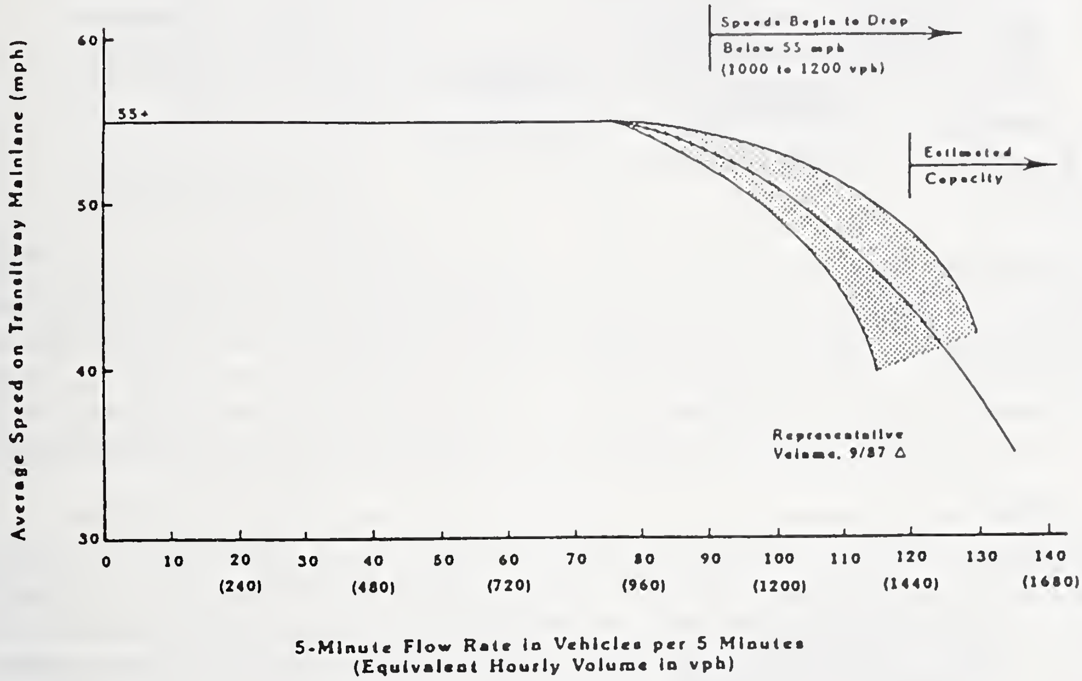
* It is worth noting, moreover, that operations in this range are much more sensitive to incidents (accidents, bad weather, etc.) and that thus system reliability would be significantly impaired. "At a volume of approximately 1,500 vph, average transitway speeds drop below 40 mph. Also as transitway volumes increase, the delay that results from transitway incidents increases substantially" (TTI, 1987, p. vi).

Figure 10-8. Speed-Volume Relationship for the Katy Transitway (Volume not Impacted by Downstream Bottleneck)



Source: TTI (1987).

As Figure 10-9 reveals, the decision to allow all 2+ carpools to use the Katy Transitway resulted in substantial short run increases in the numbers of persons using the transitway. The critical issue, however, is whether the resulting deterioration in transitway performance is consistent with achieving maximum passenger volumes in the long run. At the time the TTI "Options" report was prepared it appeared that METRO and SDHPT, in their rush to cater to motorists, had decided to throw the baby out with the bath water. Fortunately, METRO rejected TTI's recommendation, albeit with a one year lag.* Beginning October 27, 1988, only 3+ carpools were permitted to use the Katy Transitway during the AM peak period; the 2+ rule was maintained for the PM peak period, however.

TTI analysts also prepared estimates of the effect of four alternative demand strategies on peak-hour carpool volumes. The resulting policies and the estimated impacts on carpool use are:

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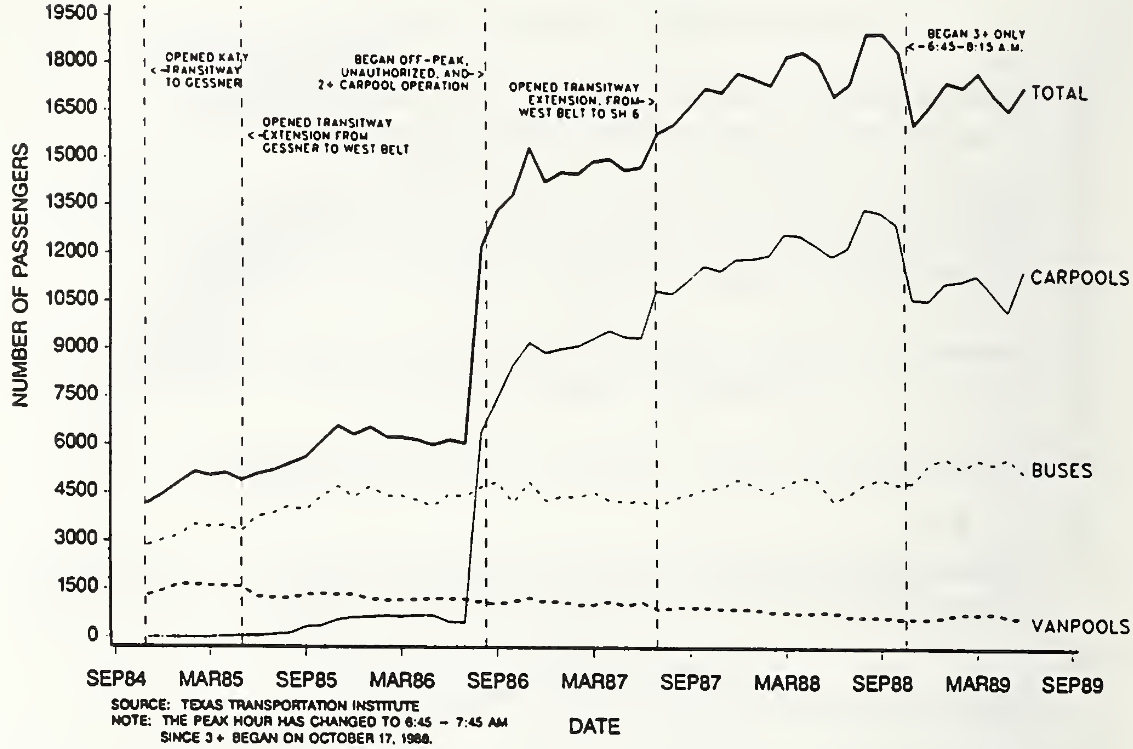
* According to Paul Bay, METRO's Assistant General Manager for Planning, the decision to implement the 3+ rule during the AM Peak was made by METRO's new Board Chairman, Robert Lanier, during the week of October 17th against the advice of TTI analysts and METRO staff. METRO staff were in the process of preparing an options paper urging steps similar to those recommended by TTI, when Lanier made the decision.

Figure 10-9. Number of Daily Person Trips Using the Katy Transitway by Mode (September 1984 - September 1989)



Source: TTI (1986a).

1.	Voluntary spreading of the peak hour	0-3	percent
2.	Impose a 3+ carpool definition during the peak hour	75	percent
3.	Require peak hour vehicle authorization	20-40	percent
4.	Close and/or meter entrance ramps during the peak hour	25+	percent

The TTI report recommended against restricting use of the Katy Transitway to 3+ carpools, in large part because they anticipated that implementing the 3+ requirement during the peak hour would cause a 75 percent decline in carpool use, an impact they judged was simply too large. The TTI report stated:

> It is recommended that the alternative of changing the peak-hour carpool definition to 3+ be rejected at this time. The impacts of this alternative on demand are too drastic for implementation at any time in the foreseeable future. The alternative of a 3+ carpool definition could reduce demand by up to 75 percent to 80 percent, far in excess of the demand reduction (10-20 percent) needed to effectively manage volumes. ...

> Two other basic options exist. ... authorization during the AM peak hour. ... (or) ... selected ramp closures and or metering during the AM peak hour. ...
>
> In the opinion of the TTI research staff, at the level of knowledge that currently exists, neither is obviously superior to the other. It may be that authorization is a preferred approach for 'routine' demand management, and that ramp closures and/or metering represent a preferred approach for managing incidents and unusual operational experiences. At the volumes currently using the transitway, it is essential that incidence management strategies be developed and implemented (TTI, 1987, p. x).

Table 10-4 compares December 1988 average daily vehicle and person use of the Katy Freeway to comparable data for October 1988, the month prior to the time the 3+ carpool rule was implemented for the AM peak period. These data show that following the implementation of the policy, daily volumes vehicle using the Katy Transitway decreased by 21.5 percent while person movements declined only 9.8 percent in the same time span. As the person trip data in Figure 10-8 indicate, daily person trips using the Katy Transitway are slowly increasing.

Houston's experience with 2+ carpools on the Katy Transitway demonstrates the importance of being able to control access to shared bus and carpool facilities through carpool occupancy criteria, authorization, metering, tolls or other means to insure that transit speed, performance, and reliability are kept at high levels. Serious consideration should be given to ramp designs that permit access to be controlled, even at significantly higher capital cost. Experience in several cities with HOV facilities illustrates that it is very costly and difficult to incorporate these access controls at a later time. At the same time, authorization may produce equally satisfactory results at far lower cost and provide significant operational advantages as well.

Table 10–4. Katy Transitway Utilization as of October and December 1988

	Buses	Vanpools	Carpools	Total
Vehicles				
December 1988				
AM Peak Hour (3+ CP)	41	25	872	938
PM Peak Hour (2+ CP)	38	19	1,065	1,122
Daily (2+ & 3+ CP)	167	86	4,826	5,079
Daily, Oct. 1988 (2+ CP)	166	79	6,227	6,472
Daily, last yr. (2+ CP)	156	104	5,469	5,729
Persons				
December 1988				
AM Peak Hour (3+ CP)	1,585	194	2,102	3,881
PM Peak Hour (2+ CP)	1,350	125	2,275	3,750
Daily (2+ & 3+ CP)	5,500	619	10,653	16,772
Daily, Oct. 1988 (2+ CP)	4,830	623	13,042	18,495
Daily, last yr. (2+ CP)	5,010	904	11,930	17,844

Source: TTI (Texas Transportation Institute), 1989b.

The Gulf Transitway

During Fiscal Year 1980 METRO reached agreement with SDHPT to jointly develop a transitway in the median of the Gulf Freeway (I-45 South), as part of the SDHPT's project to widen the freeway. Studies of a transitway in the median of the Northwest Freeway began in 1983 (METRO, 1984a).

Current plans (METRO, 1989a) for the Gulf Transitway are for a barrier separated, one-way, reversible HOV lane in the median of the Gulf Freeway from downtown Houston to Choate Road (near FM 1959), a distance of 15.5 miles. In May 1988, METRO opened the first 6.2 miles of the transitway (Figure 10-3) from Lockwood to Broadway, including an elevated Eastwood Interchange T-Ramp; the Eastwood Transit Center (an 11 bus bay facility) and the I-610 interchange (at-grade ramps) were completed in October 1986. Phase 2, the 2.5 mile segment from downtown to Lockwood was completed in May 1988.

Eighty percent of the cost of the Gulf Transitway was paid for by SDHPT, as part of its Gulf Freeway reconstruction program. METRO apparently had relatively little to do with designing or implementing the Gulf Transitway and did not even participate in the preparation of an EIS for the project. Indeed, METRO's Assistant General Manager for Planning Paul Bay, when we asked about a Gulf Transitway EIS, observed that it had been prepared by SDHPT and, as far as he could recall, he had never even seen it.

When completed, the Gulf Transitway will extend a distance of 15.5 miles from downtown Houston to Choate Road. Elevated interchanges will provide access to one park and ride facility, two vanpool staging areas, and the Lockwood Transit Center. The interchanges will provide access to downtown Houston, the University of Houston, I-610, Monroe Road leading to Hobby Airport, and the South Belt (Beltway 8).

Table 10-5 gives the number of vehicles and persons by type that were using the Gulf Transitway during the AM and PM peak hour and the entire day in December 1988, eight months after the first segment opened. At that time, 5,369 persons a day were using the completed segment. The most recent data available to us (August 1989) point to some growth as the Gulf Transitway was carrying an average of 6,908 persons per day in 113 buses, 44 vanpools, and 1,482 2+ carpools. The effectiveness of the completed 6.5 mile (Phases 1 and 2) segment of the Gulf Transitway is limited by the fact that the widening of the same segment of I-45 to four general traffic lanes in each direction has insured, for the time being at least, that speeds on the adjacent freeway mainlanes are nearly as good, if not better, than transitway speeds. METRO officials expect that ridership on the Gulf Transitway will increase substantially when Phase III, i.e. from Broadway to Choate Road, a more heavily congested segment of the freeway, is completed.

The Northwest Transitway

Studies of a transitway in the Northwest Freeway median were apparently initiated in 1983 and an Environmental Assessment for the project was completed in August 1984 (METRO, 1984a). According to METRO, "the proposed action and preferred alternative is the construction of a transitway within the rights-of-way of US 290 (Northwest Freeway) and I-610 (West Loop) in

Table 10–5. Gulf and Northwest Transitways Utilization, December 1988

	Buses	Vanpools	Carpools	Total
Gulf Transitway				
Vehicles				
AM Peak Hour	24	15	451	490
PM Peak Hour	27	12	333	372
Daily	104	42	1,278	1,424
Persons				
AM Peak Hour	740	87	960	1,787
PM Peak Hour	630	72	700	1,402
Daily	2,410	255	2,704	5,369
Northwest Transitway				
Vehicles				
AM Peak Hour	12	18	638	668
PM Peak Hour	11	8	285	304
Daily	51	44	1,749	1,844
Persons				
AM Peak Hour	380	117	1,324	1,821
PM Peak Hour	340	46	599	985
Daily	1,300	295	3,688	5,283

Source: TTI (Texas Transportation Institute), 1989b.

Northwest Houston between a point east of FM 1960 and I-10 (Katy Freeway), a length of approximately 13.5 miles" (METRO, 1984b). The EIS describes the proposed project as a one-lane reversible transitway for 11.9 miles from south of FM 1960 to Dacoma Avenue plus a two-directional segment from approximately Dacoma Avenue and along the West Loop to the Northwest Transit Center (ibid, p. 2-18). The report adds that buses and authorized vanpools would have access to the transitway.

Following UMTA guidelines, METRO evaluated a No Build and a Transport System Management Alternative in addition to the Northwest Transitway. Table 10-6 provides summary statistics comparing the Transitway Alternative to No Build and TSM Alternatives. As these data reveal, the extent of transit services provided and ridership levels observed are 30 to 50 percent greater for the Transitway than for the No Build Alternative. Comparisons of the Transitway and the TSM Alternative are more meaningful. They indicate that the Transitway was expected to serve about 12 percent more transit riders in the Year 2000 than the TSM Alternative, would have had operating costs per passenger that are essentially identical, but would have had capital costs that are 15 percent higher. The total cost per passenger (operating cost plus annualized capital costs per passenger) was predicted to be about three percent higher for the Transitway than for the TSM Alternative.

A September 1987 report by METRO on the status of its transitway projects indicates that, in contrast to the Gulf Transitway, which was paid for primarily by SDHPT and UMTA, METRO paid a significant share, about one third, of the cost of the Northwest Transitway. Of an estimated total cost (1989 dollars) of $125.1 million, UMTA paid $73.3 million, METRO paid $45.1 million, and SDHPT paid $6.7 million (METRO, 1987c).

Table 10–6. Characteristics and Operations of the Northwest Transitway Project, Houston, August 1984 (Dollar Figures in 1989 Dollars)

Project Characteristics	No Build	TSM	Transitway	TW/NB	TW/TSM
Regional System Characteristics 2000					
Total Vehicle Miles (millions)	54,624	79,997	82,038	1.50	1.03
Total Vehicle Hours (000's)	3,610	5,190	5,229	1.45	1.01
Park and Ride Lots	25	26	27	1.08	1.04
Transitways	3	3	4	1.33	1.33
Maintenance Facilities	6	9	9	1.50	1.00
Bus Operating Costs (000's of dollars)	$198,900	$276,400	$279,400	1.40	1.01
Transit Work Trips per Day	169,873	239,106	242,415	1.43	1.01
Total Transit Trips per day	248,610	328,077	331,638	1.33	1.01
Total Corridor Related Trips	15,663	23,283	26,032	1.66	1.12
Corridor to CBD Transit Trips	6,308	9,015	9,840	1.56	1.09
Corridor to other MAC Transit Trips	3,580	5,406	6,436	1.80	1.19
Regional Vanpool Person Trips	33,361	32,158	33,701	1.01	1.05
Project Evaluation Measures, Year 2000					
Operating Cost/Transit Passenger	NA	$3.26	$3.26	NA	1.00
EUAC Capital Cost/Transit Passengers	NA	$0.77	$0.89	NA	1.15
Total Cost/Transit Passenger	NA	$4.03	$4.15	NA	1.03

Source: METRO, "Northwest Freeway Transitway Environmental Assessment," August 1984.

The first operational segment of the Northwest Transitway began accepting vehicles in August 1988, three months after the first segment of the Gulf Freeway became operational. Use of the Northwest Transitway has been limited by the fact that vehicles using it have had to make a time consuming detour to leave or enter the transitway at the inner end. Even so, as Table 10-5 reveals, the number of persons using the Northwest Transitway each day in December 1988, was only slightly less than the number using the Gulf on the same day. By March 1989 the number of daily users of the Northwest Transitway had increased slightly to 5,379 (from 5,283 in December 1988), and the number of daily bus riders had increased from 1,300 (December 1988) to 1,690 in (March 1989).

When it is finally completed, the Northwest Transitway (Figure 10-3) will be a 13.5 mile HOV lane for the use of buses, vanpools, and carpools. The segment from FM 1960 to Loop I-610 is an at-grade, one-lane reversible HOV lane (approximately 20 foot wide) within the median of US-290. At Loop I-610, the guideway changes to an aerial two-lane, two-way 38 foot wide configuration until it ends at the Northwest Transit Center. Approximately 10.5 miles of the 13.5 mile transitway will be at grade and 3.0 miles will be elevated. The aerial segments provide direct, grade separated controlled ramp access to three park and ride lots, the Brookhollow Office Complex, and the Northwest Transit Center. The Northwest Transitway is being built in two phases. Phase I, the 9.5 mile segment from West Little York Road to the Northwest Transit Center at Old Katy Road near I-610 was completed in August 1988. Phase II, the four mile segment from near FM 1960 to West Little York Road, was completed during 1989.

The Southwest Transitway

METRO's 1984 Annual Report refers to the beginning of studies of the possibility of building a transitway in the median of the Southwest Freeway, presumably in the previous year. By the end of September 1985, METRO and SDHPT had completed the Final EIS for a proposed Southwest Freeway/Transitway project that would "widen and improve US 59 (Southwest Freeway) from Beltway 8 to State Highway 288 (SH 288)" (METRO, 1985, p. S-1). In addition to the preferred alternative, shown in Figure 10-10, the study evaluated No-Build and TSM Alternatives.

Table 10-7 provides summary statistics comparing the proposed Southwest Transitway to the No Build and TSM Alternatives. These comparisons reveal that the Transitway Alternative would provide a significant expansion in transit services over those included in the No Build Alternative and, according to METRO's ridership projections, would induce much higher levels of transit ridership. Regionwide transit trips in 2005, including vanpools, were projected to be 30 percent larger with the Southwest Transitway than without it, i.e the No Build Alternative, and corridor trips were projected to be 48 percent higher.

Figure 10-10. Southwest Freeway/Transitway Project Build Alternative (October 1985)

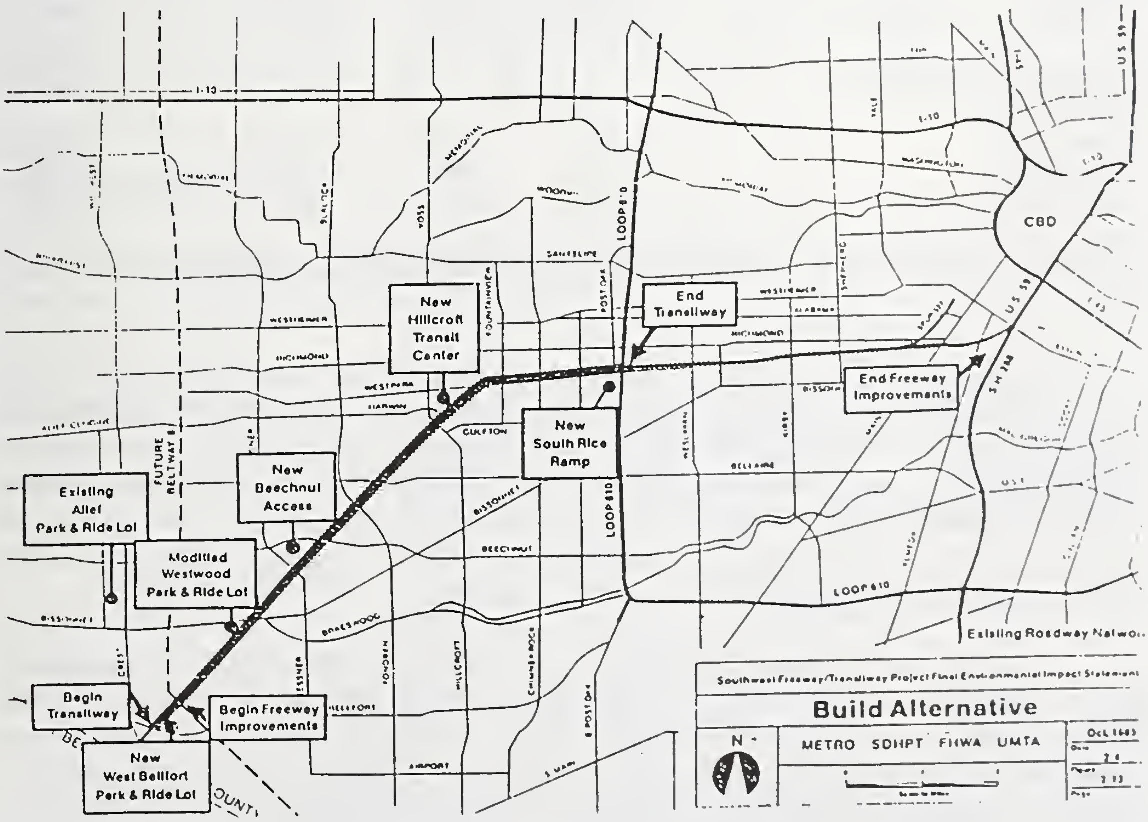


Table 10–7. Characteristics of the Southwest Freeway/Transitway Project October 1985 (Dollar Figures are in Millions of 1989 Dollars)

Characteristic	No Build	TSM	Transitway	TW/NB	TW/TSM
Capital Cost (millions of dollars)					
Southwest Corridor Improvements	$0.0	$128.9	$128.9	NA	1.00
Corridor Transit Facilities	$0.0	$0.0	$97.3	NA	NA
Transit Service Characteristics (Year 2005)					
Daily Vehicle Miles of Travel–Corridor					
Local Bus	15,092	22,347	20,343	1.35	0.91
CBD Express Service	38,806	51,424	57,220	1.47	1.11
Post Oak Express Service	5,225	11,653	14,121	2.70	1.21
Greenway Plaza Express	0	3,942	6,118	NA	1.55
Total	59,123	89,366	97,802	1.65	1.09
Transit Ridership Per Day (Year 2005)					
Corridor Related					
Work	40,200	58,300	63,800	1.59	1.09
Vanpool	3,600	3,400	4,100	1.14	1.21
Total	55,100	75,700	81,700	1.48	1.08
Total Region					
Work	187,000	265,000	270,000	1.44	1.02
Vanpool	36,000	35,000	35,000	0.97	1.00
Total	310,000	399,000	404,000	1.30	1.01
Systemwide Costs and Revenues (millions of dollars)					
Farebox Revenue	$57.6	$88.5	$96.0	1.67	1.08
Operating Costs	$224.4	$304.1	$305.7	1.36	1.01
Operating Deficit	$166.8	$215.6	$209.7	1.26	0.97

Source: METRO and SDHPT, "Final Environmental Impact Statement Southwest Freeway/Transitway Project," Oct. 198

Differences between the Transitway and TSM Alternatives were much smaller. The Transitway Alternative assumed nine percent more vehicle miles of service would be supplied in the corridor with the Transitway than with the TSM Alternative. These service expansions and the transitway improvements increased transit trips within the corridor by about eight percent. Farebox revenues for the Transitway Alternative were about eight percent higher as well, but operating costs increased by only one percent. As a result the operating deficit was only 97 percent as large for the Transitway as for the TSM Alternative.

The Southwest Transitway will be the next to last of the currently planned transitways to open for operation. This is in spite of the fact that the Southwest corridor is the most heavily traveled corridor and the one with the worst congestion. This apparent anomaly is explained by the fact that METRO was saving the Southwest Corridor for its heavy rail system. Serious planning for a transitway in the Southwest Corridor only began when it became clear to METRO that it would not be able to build a large heavy rail system in the foreseeable future.

The Southwest Transitway, as currently planned, is being built in five segments from the outside-in. In contrast to the Southwest Transitway design shown in Figure 10-10, which stopped at Loop I-610, the current plan is to continue the transitway all the way into downtown. The current design is for a 20.5 foot wide, one lane reversible facility constructed primarily at grade in the median of the Southwest Freeway. The project, as currently designed, also includes a new park and ride facility at West Belfort Avenue with about 1,000 parking spaces, and a new transit center near Hillcroft with about 1,100 spaces. The scheme would also modify the existing Westwood park and ride lot to provide direct access to the transitway. Users will be able to enter and leave the Southwest Transitway at seven locations: freeway access/egress ramps at Wilcrest; grade separated T-ramps at the West Belfort park and ride lot; the Westwood park and ride lot; Hillcroft Transit Center; an at-grade ramp to Westpark at I-610; freeway access/egress ramps at New Castle and Shepherd; and a slip ramp inside of the I-610 Loop west of Wesleyan. Additional access/egress ramps would be provided at Spur 527 when the transitway is extended. All ramps have been designed to accommodate two-way operation of the transitway.

The transitway will be constructed in conjunction with the SDHPT's planned reconstruction of the Southwest Freeway from the Fort Bend County/Harris County line to SH-288. According to METRO's April 1989 "Briefing on METRO Transitway Projects" (p. 17), it is anticipated that construction of all freeway and transitway facilities, from West Belfort to a point in the vicinity of New Castle, will be accomplished in the period Summer/Fall 1989 to Winter 1992. The segments, from Wilcrest to West Belfort and from the vicinity of New Castle to Shepherd will be completed approximately a year later. The schedule of the remaining segment from Shepherd to Spur 527 is to be determined. As the ridership data in Table 10-3 indicate, as of July 1987 METRO expected the Year 2000 transit ridership for the Southwest Transitway to be 31,000 passengers per day. Carpool use is now a virtual certainty.

The Eastex Transitway

As we discussed previously, the Eastex Transitway is a very recent addition to METRO's transitway development program and thus very little information is available about it. It is clear, however, that construction of the Eastex Transitway, shown in Figure 10-3, will be done in conjunction with SDHPT's reconstruction of the Eastex Freeway. The entire project consists of freeway improvements from downtown Houston to Cleveland in Harris County and a 20 mile two-lane, two way HOV lane from downtown to south of Kingwood Drive. In addition to ramps downtown and at a point near Kingwood Drive, current plans include five intermediate access points to the transitway at Kelly Street, Tidwell, Eastex, Will Clayton, and Townsen Interchange.

SDHPT and METRO plan to build the transitway in three phases. Segment IB, the first phase of the Eastex Transitway program, will be a 10.7 mile segment from I-610 to north of Beltway 8 and is scheduled to be completed in mid-1994. Segment IA, the second Phase in terms of time to completion, will extend 3.5 miles from the CBD to I-610, and is currently scheduled to be completed in mid-1995. SDHPT received a finding of no significant impact (FONSI) from the Federal Highway Administration in December 1988 for a project to widen and upgrade US 59N from downtown to the Cleveland By-pass. Provisions for the Eastex Transitway were included in the schematic design and environmental assessment. Phase III, i.e. Segment II,

which will extend from Beltway 8 to a slip ramp south of Kingwood Drive will be 5.8 miles long. No date has been set for its completion.

Passenger Volumes: Transitways vs. General Traffic Lanes

Houston's transitways are meant to increase the productivity of the region's freeways, particularly during peak hours. The idea is to encourage commuters to use modes of travel, i.e. buses, vanpools, and carpools, that conserve on precious and costly roadway space. By providing peak-hour speeds significantly higher than those in congested freeway general traffic lanes, commuters are induced by the HOV lane time savings to make their trips by bus, vanpool, or carpool.

Further discussion of the effect of time savings on transit use, vanpooling, and carpooling is presented in Chapter 15. At this point, however, we review the evidence provided by the Houston "experience" on the productivity of Houston's transitways and the effect of the time savings they provide on transit use and ridesharing. Figure 10-11 encapsulates the argument for HOV facilities. These data indicate that the single HOV lanes on the North and Katy freeways in Houston both carried more than four thousand persons during the AM peak hour on an average day in 1987.* The three peak-direction general traffic freeway lanes by comparison carried an average of less than 1,800 persons during the same time period.

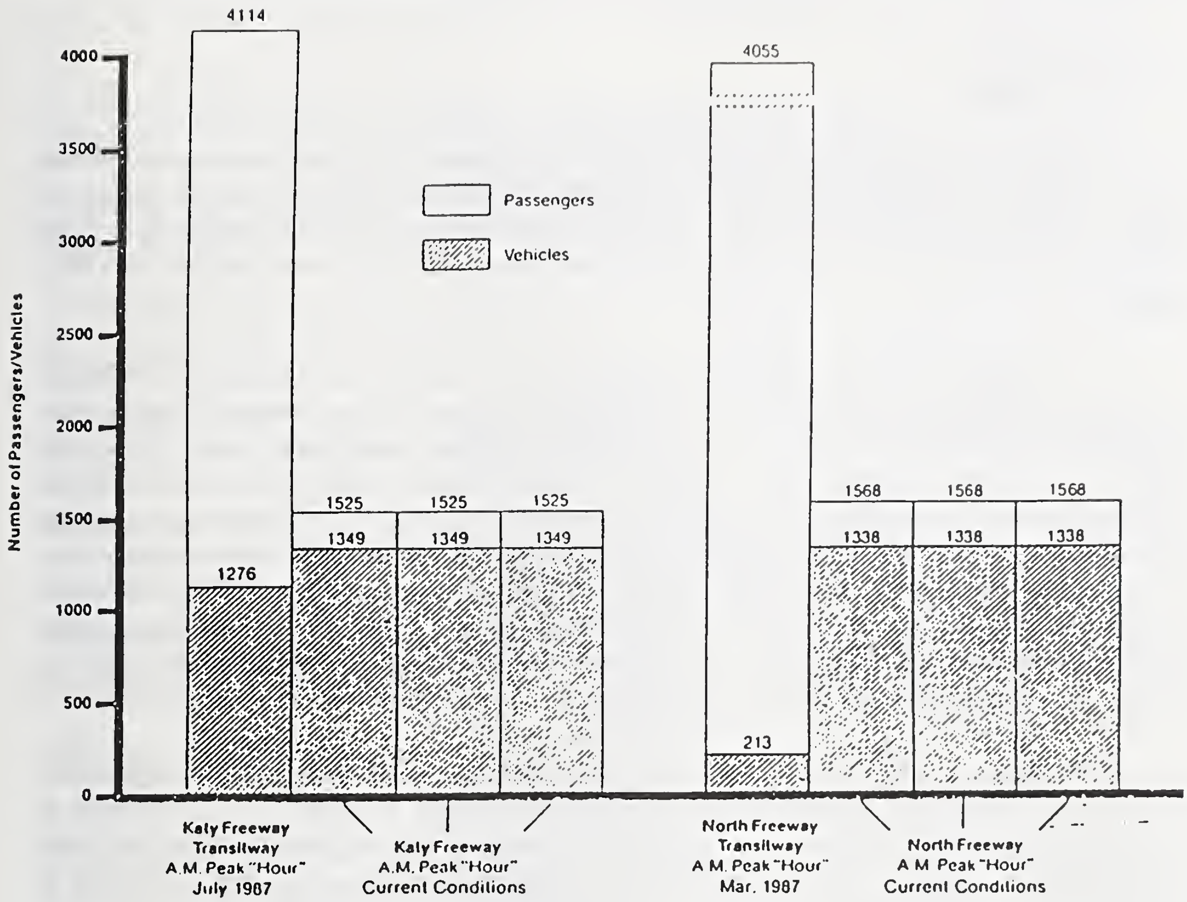
As the statistics in Figure 10-11 indicate, while the Katy and North Transitways carry almost identical numbers of persons during the AM peak and about three times the number carried by each of the peak direction general freeway lanes, they achieve these results in very different ways. The North Freeway carries its four thousand persons in only 213 vehicles, while the Katy requires 1,276. The explanation, of course, is that most users of the North Transitway make their trip by bus, while most Katy Transitway peak hour commuters are in two person carpools. During March 1987 bus passengers were 70 percent of the 13,794 daily users North Transitway with the rest being accommodated in vanpools. During July 1987 bus riders accounted for only 26 percent of the 16,528 daily users of the Katy Transitway, while carpools accounted for 69 percent.

The North Transitway, which does not allow carpools, still has significant amounts of excess capacity, while the Katy Transitway when it permitted 2+ person carpools during the AM Peak was close to or beyond its practical capacity. As we discussed previously, METRO corrected this problem in October 1988 when it decided to restrict AM peak period use of the facility to 3+ carpools.

It is more difficult to determine how many of the users of the North and Katy Transitways were induced to use buses, vanpools, and carpools by the time savings afforded by the transitways. The problem is distinguishing between individuals who are induced to rideshare by the

* These data refer to the period before the 3+ carpool rule was implemented. As we reported earlier in this chapter, only 3,881 persons were carried in the Transitway during the AM period in December 1988. This is still twice the number being carried in the freeway mainlanes. In addition, the numbers using the transitway are certain to grow as travel demand in the corridor increases; the freeway main lanes in contrast, are operating at their capacity already and thus have little potential to carry more persons unless mainlane vehicle occupancy rates increase.

Figure 10-11. Relative Lane Utilization: Katy and Northwest Freeways/Transitways



Source: METRO (1987c).

transitway and those that previously commuted by bus, vanpool, or carpool and simply shifted to the transitway when it opened. Christiansen and Ranft (1986, p.50) report that experience in Houston indicates that each 10 percent reduction in travel time resulting from a new or improved HOV facility will increase ridership on the facility by 4.5 percent. This estimate, however, is a gross rather than a net elasticity, since it measures changes in ridership on the transitway rather than changes in the numbers of persons ridesharing.

Christiansen and Ranft (1988) also present comparisons of peak hour occupancies in Houston freeways with and without ridesharing. They find that peak-hour vehicle occupancies on the North and Katy Freeways (including both the transitway and general freeway lanes) are 1.77 and 1.53 in December 1987 respectively, while the average for the Gulf, Southwest, and Northwest Freeways, which did not have operational transitways at the time, were only 1.25, 1.20, and 1.14 (Christiansen and Ranft, 1988, p. 85). Finally, Christiansen and Ranft present

survey results for Katy Transitway carpoolers showing that 52 percent of those using the transitway in October 1987 drove alone before the transitway was opened (Ibid, p. 96). There are problems in interpreting these data as well, but they provide further support for the view that transitways, by providing a significant travel time savings, induce more transit use and carpooling.

Transitway Markets

It cannot be overemphasized that METRO's transitway, commuter services and similar radially oriented, high performance transit operations serve rather limited and narrow markets. A transit rider survey conducted by METRO in 1985 illustrates both the specialized nature of its commuter market and the huge difference between it and METRO'S local services (METRO, 1986a).

The METRO ridership survey, for example, finds that while 93.9 percent of local bus users walked to their bus stops, 89.7 percent of those using commuter services drove to their bus stop or park and ride lot and an additional 6.6 percent were driven; only 3.3 percent walked.* Of course, the nearly total dependence of those using commuter services on private cars is a direct result of METRO policy. METRO commuter routes primarily serve park and ride lots with limited local bus services, and none of METRO's park and ride lots have feeder bus services. METRO may well be correct in its judgement that it cannot provide cost-effective feeder bus services for its commuter services and that it is inefficient to use the express buses themselves for residential collection. At the same time, the policy appears to be based more on dogma than careful analysis or much experimentation.

The access modes used by local and commuter bus passengers reflect a huge difference in auto availability. The 1985 METRO transit riders survey indicates that 72.3 percent of local weekday bus riders had no auto available for their trip; the comparable figure for those using commuter services is only 10 percent. The survey reveals, moreover, that 82 percent of those using commuter services, but only 22.4 percent of local bus riders, were white. Commuter bus passengers also had much higher incomes: 71 percent had household incomes of more than $35,000 a year, as compared to only 16 percent of local bus riders. Similarly, 50 percent of local bus riders had income of less than $15,000 as contrasted with only 2.4 percent of commuter bus passengers.

As Table 10-6 indicates 95 percent of express bus users on the Katy Transitway and 94 percent of express bus users on the North Transitway were destined for downtown. Of course, this too is the result, in large part, of METRO policy and route structures, since METRO provides few services to destinations other than downtown from its park and ride lots. These data reveal, moreover, that vanpools and carpools are more effective in serving the Galleria, Texas Medical Center, Greenway Plaza, and other destinations than buses are (Bullard, 1988, p. vi.).

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* A December 1980 survey of peak period users of the North Freeway obtained similar results for the express bus operations using the North CFL. The survey revealed that 95.5 percent of bus users were headed for downtown as contrasted with 74.9 percent of vanpoolers, 66.7 percent of auto passengers, 48.5 percent of drivers of multiple occupant cars, and 29.3 percent of the drivers of single occupant vehicles. Of the remaining drivers of single occupant cars, 2.3 percent had the Texas Medical Center as their destination, 13.1 percent were headed for the Galleria area, 6.9 to Greenway Plaza, and 48.4 had other unspecified destinations (Atherton and Eder, p. 8-2).

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Chapter 11. The Extent and the Nature of Central Area Distribution

Introduction

Boosters of light and heavy rail systems frequently justify their call to spend billions for rail transit by promises of a cleaner and less congested city center. In many situations, they contend that construction of the rail systems will improve the environment of the central area by removing "unsightly, noisy, dirty, and clumsy" buses. Still others claim that buses are the primary cause of central business districts (CBD) congestion, and they add that only by building a rail system will it be possible to prevent gridlock of central area streets in some future year.

The argument that building a rail system is necessary to eliminate or prevent central area congestion takes several forms. In a surprising number of instances, policy-makers and citizens actually seem to believe that buses are the principal cause of the existing CBD congestion, and that removing them from CBD streets would substantially improve conditions. In other situations, advocates of rail systems do not contend that there is too little street space in central areas to accommodate current levels of trip making and transit use; instead, they claim that the CBD has too little street space to accommodate the numbers of buses that are projected for some future date. Less frequently, rail tunnels are justified as a way of reducing the trip times of transit users and thereby increasing transit use. These claims, however, are seldom critically examined, and surprisingly little effort has been devoted to measures that would improve bus operations on central area streets or reduce the time buses spend at bus stops while passengers alight and board. Even less attention is paid to improvements that would make waiting for buses or transferring from one bus to another less burdensome.

The objectives of this chapter are to examine bus operations in the downtowns of large North American cities. Initially, the chapter presents a discussion of the nature and extent of the problem and in particular considers the contribution of surface, mostly bus, transit in accommodating the travel demand of persons making trips to the downtown and the amount of street capacity used by surface transit. Afterward, the subject of central area bus capacity is analyzed; particular attention is paid to simple measures that would increase the bus carrying capacity of individual streets.

The two following chapters examine the experience in North American cities with low-capital and then more capital intensive approaches to improving downtown distribution for bus systems. The less capital intensive approaches discussed in Chapter 12 include various traffic engineering improvements, bus lanes, and transit malls. Chapter 13 discusses more capital intensive approaches, particularly bus tunnels and people movers.

Bus Use of CBD Streets

The idea that buses are the principal cause of central area congestion does not bear much scrutiny. Even the most casual analysis of bus and auto volumes demonstrates that buses use only a small fraction of CBD street space in most cities. Buses are undoubtedly per-

ceived as being the primary cause of central congestion because, being much larger and less maneuverable than automobiles, they are a highly visible presence in central areas. Analysis of 1980 Census data on trips made to work in the CBD by mode in 37 of the largest United States cities, however, clearly demonstrates that the notion that buses are the principal cause of central area congestion is simply incorrect.

Census data on the numbers of worktrips made to the central business districts of large American cities, as shown in Table 11-1, are less than ideal measures of downtown street use, but they have the enormous advantage of having been collected in a consistent manner. These data, which are 1980 Census statistics on the numbers of persons commuting to the central business districts of the nation's largest cities by mode, are used to develop estimates of the peak period use of CBD street space by autos and bus/streetcars.

The 37 cities in Table 11-1 are ranked by total CBD employment from New York City, which tops the list with nearly 445,000 jobs, to Fort Worth, Texas which had slightly over 21,400 CBD jobs in 1980. These data understate total CBD employment levels since they include only those individuals sixteen years and over who both live in the SMSA and work in the CBD, and exclude persons who did not report their place of work.*

While an undercount of CBD employment may create problems for some purposes, the general conclusions reached here are not affected. The extent of undercounting is probably relatively similar from one CBD to the next, with the exception of the areas listed above, and thus does not seriously affect the value of these data for the analyses presented here. The 1980 Census data, then, provide a rough measure of the relative levels of peak period demand for street space in different central business districts, the relative contributions of private cars and buses in accommodating this demand, and the relative amounts of street space required by each mode.

Persons making trips to and from work are the predominant users of CBD streets during peak hours. Still, residents make significant numbers of trips to central areas during peak periods for other purposes, and they contribute to central area congestion as well. These trips occur particularly during the PM peak, but since the PM peak period is longer than the AM peak, the largest hourly volumes generally occur during the AM peak.** In addition, some fraction of central area street space is used by "through trips," i.e. trips which use CBD streets, but which have both their origin and destination outside the CBD. The fraction of through trips varies considerably from one area to another, depending principally on the characteristics of each area's street system.*** It is unlikely that an explicit accounting for the complications enumerated above would significantly alter the conclusions suggested by Table 11-1.

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* A particularly acute problem arises when there is more than one SMSA in a single geographic area, San Francisco/San Jose/Oakland and Dallas/Fort Worth for example. In the case of Dallas, Texas adding persons living outside of the SMSA, but working in the CBD, and making an allowance for place-of-work not reported, increases the CBD employment in 1980 to 116,000, or by 49 percent. Since the Dallas MSA and the adjacent Fort Worth-Arlington, Texas MSA are classified as different metropolitan areas, the numbers commuting to the Dallas CBD from residents outside the Dallas MSA are probably unusually large.

** In discussing bus operations, the fact that passenger and vehicle volumes are usually larger in the morning peak hour, than in the evening peak hour, is offset set to some extent by the fact that it takes buses longer to load passengers in the evening than it does to discharge them in the morning.

*** With the construction of by-passes and inner beltways in most large urban areas, through traffic has become much less important. It is still a factor in some smaller cities, however.

Table 11–1. CBD Worktrips by Mode, Buses Required, and Estimated Share of CBD Street Space Used by Buses in Thirty–Seven Large Cities

	Mode Choice for CBD Work Trip				Percent	Bus Share			Bus Share	
City	All	Auto	Bus	Rail	Transit	of Transit	Cars	Buses	PCU 3	PCU 5
New York City	445,575	40,625	71,538	288,260	80.7%	19.9%	27,265	2,044	36.7%	54.5%
Chicago	276,235	66,415	63,923	140,855	74.1%	31.2%	52,710	1,826	18.8%	29.5%
Philadelphia	171,341	53,722	34,842	68,151	60.1%	33.8%	42,637	995	13.1%	20.9%
San Francisco	161,441	56,274	70,004	21,118	56.4%	76.8%	41,684	2,000	25.2%	38.7%
Washington, D.C.	124,510	63,746	32,054	21,024	42.6%	60.4%	43,963	916	11.8%	18.9%
Los Angeles	122,801	89,447	30,302	22	24.7%	99.9%	74,539	866	6.7%	11.0%
Houston	102,240	85,894	15,325	0	15.0%	100.0%	66,072	438	3.9%	6.4%
Pittsburgh	97,094	43,994	50,365	703	52.6%	98.6%	34,104	1,439	22.5%	34.8%
Cleveland	88,174	47,629	34,619	3,671	43.4%	90.4%	39,691	989	13.9%	22.2%
Boston	82,686	28,235	18,771	29,550	58.4%	38.8%	22,232	536	13.5%	21.5%
Dallas	78,349	59,734	17,995	0	23.0%	100.0%	47,787	514	6.3%	10.2%
Detroit	75,872	54,893	18,694	939	25.9%	95.2%	44,994	534	6.9%	11.2%
New Orleans	68,786	45,886	19,683	20	28.6%	99.9%	36,131	562	8.9%	14.4%
Atlanta	67,996	48,649	17,820	3,540	31.4%	83.4%	40,541	509	7.3%	11.8%
Minneapolis	65,936	34,729	29,320	0	44.5%	100.0%	28,235	838	16.3%	25.8%
St. Louis	65,844	47,184	17,576	0	26.7%	100.0%	36,863	502	7.9%	12.8%
Indianapolis	65,327	56,697	7,549	0	11.6%	100.0%	44,643	216	2.9%	4.7%
Denver	54,432	35,342	16,920	0	31.1%	100.0%	28,502	483	9.7%	15.6%
Cincinnati	53,369	34,801	17,527	12	32.9%	99.9%	26,978	501	10.6%	17.0%
Baltimore	53,336	31,835	19,690	36	37.0%	99.8%	23,936	563	13.2%	21.0%
Columbus	51,791	39,146	11,707	0	22.6%	100.0%	31,068	334	6.3%	10.2%
Seattle	51,781	25,537	24,285	10	46.9%	100.0%	20,594	694	18.4%	28.8%
Milwaukee	45,092	29,553	13,790	0	30.6%	100.0%	23,642	394	9.5%	15.4%
Phoenix	41,453	35,705	3,359	0	8.1%	100.0%	31,320	96	1.8%	3.0%
Portland, OR	37,928	19,812	16,248	0	42.8%	100.0%	15,478	464	16.5%	26.1%
San Antonio	37,803	31,703	5,388	0	14.3%	100.0%	26,641	154	3.4%	5.6%
Buffalo	37,516	25,114	11,395	0	30.4%	100.0%	20,418	326	9.1%	14.8%
Tulsa	34,247	30,316	3,042	0	8.9%	100.0%	25,476	87	2.0%	3.4%
Oklahoma City	33,055	30,780	1,439	0	4.4%	100.0%	26,308	41	0.9%	1.6%
Nashville	30,986	26,421	3,997	0	12.9%	100.0%	21,137	114	3.2%	5.3%
Kansas City	29,775	22,935	6,575	8	22.1%	99.9%	18,348	188	6.0%	9.7%
San Diego	29,081	23,882	3,982	16	13.7%	99.6%	20,069	114	3.3%	5.5%
Oakland	29,011	18,490	5,070	3,558	29.7%	58.8%	15,538	145	5.4%	8.9%
Honolulu	26,663	19,171	6,054	0	22.7%	100.0%	14,747	173	6.8%	11.1%
Memphis	22,574	19,081	3,142	10	14.0%	99.7%	15,901	90	3.3%	5.5%
Miami	21,743	16,504	4,684	0	21.5%	100.0%	13,753	134	5.7%	9.3%
Fort Worth	21,422	19,615	1,496	0	7.0%	100.0%	16,623	43	1.5%	2.5%
37 City Avg	78,467	39,446	19,734	15,716	31.2%	88.8%	31,367	564	9.7%	15.4%

Note: PCU is "passenger car equivalent unit."

Source: 1980 U.S. Census, by SMSA.

Trucks, important users of CBD streets, are also excluded from the journey-to-work data. Their requirements for street space are disproportionate to their numbers, because like buses they are larger and less maneuverable than autos, and in addition they occupy curb space (as well as space in other lanes if they are double parked) for extended periods of time. At the same time, trucks tend to avoid peak hours. The effect of acknowledging the presence of

trucks on CBD streets, like non-work and through trips, further reduces the estimated share of city street space used by buses. Both peak period non-worktrips to CBDs and through trips have a higher auto mode split than worktrips. This conclusion is supported by cordon count data for 12 large cities discussed at a later point in this chapter. Finally, Census data most likely overstate the peak period transit mode split somewhat as virtually all worktrips made by persons living outside the SMSA are made by car.

Keeping the qualifications identified above in mind, the data in Table 11-1 indicate the relative levels of peak-period demand for CBD street space and the relative roles of private autos and buses in accommodating peak hour demand. Most importantly, they provide a measure of the relative use of CBD street space by buses and private cars, and thus of their relative contributions to CBD congestion.

Census journey-to-work data in Table 11-1 give the numbers of workers commuting to work by car, by bus, and by rail transit, as well as the percent of CBD worktrips by transit and the percent of total transit trips by bus. As these data indicate, the 1980 transit mode split of CBD worktrips varies greatly from close to 81 percent of total trips in New York City, to just over 31 percent in Atlanta, and finally to a low of approximately 4 percent in Oklahoma City. As discussed above, these mode split figures most likely overstate transit's share of trips to the CBD.

The data in Table 11-1 demonstrate that buses are the dominant provider of transit services to central business districts for all but a small number of large cities. The bus statistics include trips by streetcars as well as buses.* These data also reveal that only nine cities had more than 3,000 rail CBD worktrips in 1980. The numbers and percentages of people commuting by rail would be higher now as the numbers of CBD workers commuting by rail in Atlanta and Washington, D.C. are currently much greater than they were in 1980.

Cities with a rail share of transit trips of over 50 percent, New York, Chicago, Philadelphia, and Boston, share some highly distinctive characteristics (Kain, Fauth, and Zax, 1978). These cities developed their rail systems several decades ago, are served by both rapid transit and commuter rail systems, and except for Boston, have the highest levels of CBD employment. Rapid transit systems in San Francisco, Washington, D.C., and Atlanta, which carry less than half of transit worktrips to the CBD, by contrast, were all built recently, CBD employment levels tend to be somewhat less, and residential densities are considerable lower. In spite of extensive rail systems, buses and streetcars still serve more than 50 percent of all transit work-places trips in these three CBDs.**

The column in Table 11-1 labeled "Buses" is an estimate of the number of bus trips that were required to serve CBD worktrips by bus in 1980. This figure is obtained by dividing the number of bus worktrips to CBD work-places by 35 (an estimate of the number of passengers

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* Combining the data for streetcars and buses can be justified by the fact that both modes operate on the streets and, more importantly, by the fact that the Census does not provide separate counts for buses and streetcars. Streetcars were a significant mode in only two cities in 1980, Pittsburgh and San Francisco.

** The figures for Atlanta are somewhat misleading. Virtually none of Atlanta's extensive rail system was in operation in 1980. While we have no data on the current fraction of transit worktrips to the Atlanta CBD that are made by rail, MARTA has eliminated most bus routes that served the CBD in 1980 and force feed these trips, many of which were no-transfer bus trips, onto the rail system. This means that the current fraction of transit trips to the CBD that are made by rail is probably considerably greater than 50 percent.

per bus during the peak period). Even though New York City's buses carry the smallest share of transit trips of any U.S. city, they are also, according to this measure, the most numerous: an estimated 2,044 bus trips were required to carry the nearly 72,000 persons who worked in Manhattan's CBD and used buses for their entire journey. The estimated number of buses (and streetcars) required for San Francisco is almost as large as for New York City, i.e. 2,000. Only two other cities, Chicago and Pittsburgh, required as many as 1,000 bus trips and only five others required more than 800.

The estimated number of bus trips required to carry Manhattan's workers include relatively few New Jersey-Manhattan express bus users. As we discussed in Chapter 3, most New Jersey-Manhattan express bus riders transfer to the subway at the Port Authority Bus Terminal and appear in Table 11-1 as subway passengers, even though most of their worktrip, in terms of miles travelled, is by bus. As noted previously, this coding convention tends to give bus transit less credit than it deserves for carrying commuters, but in this case it presumably provides a more accurate estimate of bus use of CBD streets. Virtually all of the buses using the Port Authority Bus Terminal arrive and depart by exclusive ramps and never enter the city streets.

The estimated number of automobiles required to accommodate auto worktrips to the CBD is calculated by dividing the numbers of worktrips by car by city specific auto occupancy rates. Occupancy rates, which are not shown in Table 11-1, range from a high of 1.5 persons per car for worktrips to the New York City and Washington's CBDs to a low of 1.1 persons per car for worktrips to the CBD in San Jose and Toledo. New York City's high auto-occupancy rates are the result of the high cost of garaging and operating private cars in Manhattan and the high levels of transit service, while Washington, D.C.'s reflect high parking charges, measures to encourage using carpools on local highways (see Chapter 6), and federal government incentives for using carpools.* As we discussed in Chapter 4, San Francisco, which had the third highest automobile occupancy rates for CBD worktrips, has also implemented highly successful policies to encourage carpools on the Bay and Golden Gate bridges.

The last two columns in Table 11-1, labeled "Bus Share," presents what might be thought of as the "bottom line" of this exercise. These are estimates of the relative contribution of buses to CBD congestion. The bus share figures are ratios of rather generous estimates of the amount of street space used by buses to total vehicle use measured in passenger car equivalent units (PCUs). The first bus share figure "PCU 3" assumes buses use three times as much street space as a passenger car; the second bus share "PCU 5" assumes they use as much street space as five. In each case the resulting estimate is then multiplied by two, on the assumption that buses which pass through the CBD travel more miles within the CBD than does the average passenger car used for making worktrips to the CBD. The discussion that follows will generally use the bus share figure based on the assumption that buses use as much street space as six cars, i.e. a PCU of three times two.**

* These incentives include preferential parking for carpools and staggered work schedules to accommodate members of carpools.

** A PCU of 1.5 is used for buses on an uninterrupted highway. In the city though, the figure must be higher to reflect the interference buses cause to other vehicles when they leave stops or make turns. A PCU of 5 is a fairly good number for figuring out how many cars would be removed from a given street if the street is to be converted to bus only use, but it is probably too high for situations where there is less bus activity. Three, a compromise between 1.5 and 5, is most likely a better average PCU. Our decision to multiply the bus numbers by two almost surely overstates the impact of buses on CBD street use.

With the exception of New York City, where the figure is close to 37 percent, the bus share of CBD street space is less than 26 percent. However, even infrequent visitors to New York will recognize that this estimate most likely overstates bus use of the CBD streets, since the denominator of the index includes neither taxicabs nor trucks. San Francisco with a bus share of just above 25 percent, Pittsburgh with approximately 22 percent, and Chicago with close to 19 percent are the second, third, and fourth highest ranking CBDs according to this measure. Streetcars are an unusually important mode in both San Francisco and Pittsburgh.

The estimated share of street space used by buses and streetcars exceeds 15 percent in only three other cities Seattle (over 18 percent), Portland (close to 17 percent), and Minneapolis (just above 16 percent). It may not be a coincidence that two of these three cities have implemented transit malls, and Seattle is currently building a CBD bus tunnel. Other cities with larger street shares for buses already had rail rapid transit systems in 1980 (Philadelphia, Washington, Cleveland, and Boston) or have opened a new rail system since 1980 (Baltimore).

CBD Cordon Counts

The methods used in estimating bus use of central area streets for Table 11-1 entail a number of assumptions. Cordon count data provides more direct measures of the number of buses and other vehicles in the CBD and makes the use of at least some of these assumptions unnecessary. The disadvantages of cordon count data are that data collection procedures are non-uniform and they are available for fewer cities. Even so, available cordon count data are a valuable supplement to the Census data.

Table 11-2 presents peak hour cordon counts of the numbers of vehicles entering the CBDs of 12 large United States cities. The data in column titled "Actual Buses" are the numbers of buses counted in the cordon counts. The data in the column titled "Est. Buses" (estimated buses) are estimated numbers of buses from the figures derived in Table 11-1. Cordon count data in Table 11-2 are generally consistent with the estimates presented in Table 11-1, although there are differences. In the first instance, it should be emphasized that the journey-to-work data in Table 11-1 are interpreted as an estimate of travel during the peak two hours or so, while the cordon count data in Table 11-2 are for the peak hour, except for Dallas and Ft. Worth where the data refer to a two hour peak period.

The cordon count data document the importance of truck traffic in CBDs, even during the peak hour. While these data are revealing, they are less than ideal since they provide no information on the characteristics of these trucks, i.e. their size and whether they are loading and unloading in the CBD or just passing through, factors that largely determine the amount of CBD street capacity used by individual trucks. Nonetheless, the numbers of trucks crossing the CBD cordons, exceed the numbers of buses in seven of the eight cities, in most cases by large amounts. Denver, the only city where the cordon data is for the PM peak, is the only exception.* Even though the estimates in the column "Percent of Space, trucks" in Table 11-2 are based on

* There are several possible reasons why the Denver numbers differ from those in other cities. First, Denver is the only city in the group for which the cordon counts are for the PM peak and include both entering and exiting vehicles; counts in the other cities are for entering vehicles only. This is likely to lead to a higher count for buses than for other vehicles, particularly since most truck deliveries are in the morning. Second, it is also possible that Denver has tough restrictions on truck use of CBD streets during peak hours or uses an unusually narrow definition of what constitutes a truck.

Table 11–2. Peak Hour Vehicle Crossings of CBD Cordons by Mode in Selected Cities

City	Period	Year	Total	Auto	Trucks	Actual Buses	Est. Buses	Persons Per Bus	Percent of Space Buses	Percent of Space Trucks
New York	AM	1986	60,872	54,968	(a)	1,722	1,022	40	8.6%	N/A
Chicago	AM	1983	24,942	19,427	1,857	876	913	32	9.2%	13.0%
Washington, D.C.	AM	1987	78,791	76,198	1,146	653	458	38	2.4%	2.8%
Los Angeles	AM	1978	38,684	35,500	2,518	666	433	46	4.7%	11.8%
Boston	AM	1982	43,981	41,944	2,037	N/A	268	N/A	N/A	N/A
Dallas	AM (b)	1983	48,839	46,798	1,421	620	514	41	3.6%	5.5%
New Orleans	AM	1981	15,260	14,260	389	299	281	35	5.6%	4.8%
Minneapolis	AM	1984	20,449	18,335	1,456	517	419	36	6.8%	12.7%
Denver	PM	1977	31,492	25,180	495	638	242	15	6.7%	3.5%
Milwaukee	AM	1984	19,811	19,576	(a)	235	197	N/A	3.5%	N/A
Ft. Worth	AM (b)	1983	28,973	27,874	971	128	43	19	1.3%	6.4%

Notes: (a) Included under autos. Statistics for Denver refer to entering and exiting vehicles, all other cities are entering only. Boston CBD represents "Boston Proper" and Washington D.C. CBD, the "Metro Core;" both areas are considerably larger than census CBD. Light trucks are counted as autos in Washington, D.C. Percent of street space occupied by buses and trucks is calculated with a passenger car equivalent unit (PCU) of three for buses and two for trucks.

(b) Dallas and Fort Worth cordon data are for two hours, therefore, the estimated numbers of buses for these are the same as in Table 11–1.

Source: Charles River Associates (1988). "Characteristics of Urban Transport Demand," (July).

the assumption that trucks use as much street space as two passenger cars, as compared to three and five in the case of buses, they indicate that trucks use as much peak hour street space as buses in all but two of the eight cities with cordon count data for both trucks and buses.

Actual numbers of buses are also compared to the estimated numbers of buses. Estimated numbers of buses, the column labeled "Est. Buses," were obtained by dividing the numbers of buses in Table 11-1 by two, assuming that the worktrip data roughly correspond to two peak hours (again except for the Dallas and Ft. Worth). In comparing the two numbers, it should be noted that the analysis years differ; the estimated numbers are based on 1980 Census data, while the actual numbers are from cordon counts conducted in various years, ranging from 1977 to 1987. With the exception of Chicago, the actual numbers of buses in Table 11-2 are greater than the estimated numbers, sometimes by a large amount.

The differences between the actual and estimated numbers of buses entering the CBDs may be due to several factors. First, the number of transit users in Table 11-1 is certainly too small since the data referred to only worktrips and, in addition, as we noted in our discussion of Table 11-2, the Census data underestimate the number of worktrips. Second, the fraction of worktrips made during the morning peak <u>hour</u> is almost certainly larger than one-half of the ratio assumed for the bus estimate, the bus estimate is of the number in the peak two hours, and this tendency is likely to be particularly pronounced in the case of transit. Third, average peak period ridership per bus is almost always different from the 35 assumed in the analysis for Table 11-1, and as the cordon count data indicate, there is substantial variation across cities. Fourth, bus operators may schedule more buses during the peak <u>hour</u> than the average of the peak pe-

riod. It is no coincidence that the largest percentage discrepancy between actual and estimated bus counts are obtained for Fort Worth, where most of these considerations likely apply, and, in particular, where average bus occupancy during the peak hour is reported as 19, well below the 35 passengers per bus figure used in estimating the required number of buses in Tables 11-1 and 11-2.*

Table 11-3 contains estimates of the actual number of auto or bus person-trips crossing the CBD cordons of selected cities by mode during the peak hour or period, and the number of bus worktrips to the CBD in 1980 (the figures from Table 11-1). The Census bus worktrip figures are divided by two, except for Ft. Worth and Dallas, to allow for some comparability with the cordon count numbers. While the 1983 figure for bus person trips crossing Chicago's CBD cordon is slightly smaller than the 1980 Census estimate of bus trips by CBD workers, the actual number of bus passengers exceeds the number of CBD bus worktrips reported in the Census, in some cases (Los Angeles AM peak hour in 1978 and the Dallas and Fort Worth AM peak period in 1983) by the large amounts.

Census estimates of CBD bus trips are generally smaller than cordon counts for the same cities. While the differences between census figures and cordon count figures are quite

Table 11–3. Number of Auto and Bus Person Trips Crossing the CBD Cordon of Selected Cities

Location	Period	Year	Cordon Total Persons	Cordon Persons in Buses	Adjusted Census 1980 Bus Worktrips (a)	Bus Trips Census/ Cordon
New York	AM	1986	158,343	69,590	35,769	51.4%
Chicago	AM	1983	62,819	28,071	31,962	113.9%
Washington, D.C.	AM	1987	136,274	25,044	16,027	64.0%
Los Angeles	AM	1978	85,965	30,549	15,151	49.6%
Boston	AM	1982	84,315	10,201	9,386	92.0%
Dallas	AM (b)	1983	88,093	25,195	17,995	71.4%
New Orleans	AM	1981	32,120	10,434	9,842	94.3%
Minneapolis	AM	1984	46,492	18,657	14,660	78.6%
Denver	PM	1977	57,106	9,399	8,460	90.0%
Ft. Worth	AM (b)	1983	37,831	2,434	1,496	61.5%

Notes: (a) "Adjusted Census 1980 Bus Worktrips" are peak period bus trips from the 1980 Census divided by two to approximate the number of peak hour trips, except for Dallas and Ft. Worth.
(b) Dallas and Ft. Worth cordon counts are for the two hour peak period.

Source: Charles River Associates (1988), "Characteristics of Urban Transport Demand," (July); U.S. Census (1980).

* Differences between the cordon count data and the estimated number of buses derived from Census data could also arise from different CBD definitions. The cordons in both Washington, D.C. and Boston, for example, define a much more extensive area than the definition of the CBD. A brief comparison of Tables 11-1 and 11-2 indicates that the number of autos counted in Table 11-2 is, with the exception of Los Angeles and New Orleans, is more than half of the peak period estimate of auto use obtained from the Census. In the cases of New York, Washington D.C., and Boston the peak hour number of autos in Table 11-2 exceeds the estimated peak period number in Table 11-1. Similar comparisons can be made with the number of person trips.

large they seem to be related to differences in the extent to which vehicles and transit are used for other than worktrips, differences in the extent of peaking, and the problems of defining bus trips in cities, like New York, where many individuals make multi-modal trips.

In spite of the extensive differences between journey-to-work statistics and the cordon count data and the numerous complications discussed above, the cordon count data broadly confirm the conclusions obtained from our analysis of the journey-to-work data. Although buses carry a large fraction of trips to and from downtown, they use relatively little CBD street space. The cordon count data in Table 11-2, indicate that buses crossing the CBD cordon occupied only about 8.6 percent of the street space used by vehicles crossing the New York City CBD cordon in 1986.* Similarly, in Los Angeles the cordon count data indicate buses use about 5 percent of the occupied CBD street space during the AM peak hour. While buses may occupy a small fraction of street space, they carry a very large percentage of the trips to the CBD.

The cordon count data in Table 11-3 similarly show the large share of CBD person trips that are served by buses. Buses carry over 40 percent of the person trips crossing the CBD cordon in New York, Chicago, and Minneapolis, even though they use less than 10 percent of CBD of street space in all three cities, using estimates from Table 11-2. These and similar data provide a strong argument for allocating more rather than less street space to buses.

Determining CBD Bus Capacity

Use of a single passenger equivalency factor for buses to evaluate CBD bus capacity, as in Tables 11-1 and 11-2, gives a general sense of the amount of CBD street capacity used by buses, but they may be a poor estimate of how many peak hour trips can be accommodated by an all-bus system serving the CBD of a particular city. The reason is that CBD bus capacity depends critically on a large number of factors; these factors include the size of the CBD, the number of streets and lanes serving it, the number of lanes allocated to buses, the extent and nature of vehicle turning movement restrictions (if any), the spacing and timing of signals, the number and capacities of bus stops, the distribution of passenger demand among stops, the design of equipment (particularly the number and width of doors), and fare collection procedures and policies.

When CBD bus volumes are modest, as they are in most United States cities, buses collect most of their passengers at curb-side bus stops. In such situations, effective CBD bus capacity depends principally on the number of curb lanes that are available to buses and the location and capacity of bus stops. The capacity of a curb lane used exclusively or predominantly by local buses in turn is determined by bus loading time at the busiest stop, i.e. dwell time. Dwell time can be reduced without major capital investments by changes in bus routes, equipment, CBD street signal and traffic controls, and boarding practices. Reductions in dwell times allow more buses to use a single stop and curb lane, thus increasing CBD bus capacity. Even so, the number of buses that can be used to transport riders to the CBD need not be limited by the amount of curb space.

* In this analysis, buses are assumed to use as much street space as three passenger cars.

Most central business districts with very high bus volumes make some use of terminals and other off-street facilities to board passengers and to hold buses. Even simple bus turn-outs and off-street bus loading bays can be very effective and can dramatically reduce the "presence" and visual impact of buses in the central area. Off-street boarding or bus waiting areas can be especially effective for express buses, which tend to board a large fraction of their patrons at a few stops. Such facilities are particularly appropriate for point-to-point express bus operations, like the New Jersey to New York City express buses (Chapter 3), the East Bay to San Francisco CBD bus service (Chapter 4), or the express buses serving Denver's CBD bus terminals (Chapter 12). Even without using off-street (off-line) bus terminals, bus loading, and thus bus stop capacity, can often be dramatically improved through the use appropriately designed equipment and by changes in fare collection policies.

Calculating CBD bus capacity is a demanding technical task. As in many similar analyses, the result depends in large part on assumptions (policies) that affect passenger loading and bus dwell times. None of the factors that affect dwell time are fixed; if service practices are flexible, capacity constraints are generally much less of a problem than they are often thought to be. General planning guidelines for calculating street bus capacity are contained in the Highway Capacity Manual. It indicates, for example, that a single surface (local) street lane, restricted to bus-only peak period use, has a capacity of 90 buses per lane per hour at level of service D (TRB, p.12-13). This does not mean that 90 buses per hour is the capacity of a CBD street, however.

As the data in Table 11-4 indicate, many streets in both developing and advanced countries accommodate for more than 90 buses per hour. While we know of no current situations where peak period, peak direction bus volumes on a single street in the United States exceed 200 buses per hour, streets in developing countries regularly accommodate bus volumes that are many times higher. A four lane surface street with off-line stops in Belo Horizonte, Brazil, for example, carries 1,000 buses and 86,000 passengers per hour in a single direction. Similarly, Lion Rock Tunnel Road in Hong Kong carries up to 350 buses and 23,000 passengers per hour in the peak direction in a single conventional bus lane (Transport and Road Research Laboratory, 1989). These data strongly support the conclusion that volumes of buses per lane and per street in United States cities are determined more by policy and demand, rather than by physical constraints.

As the data for cities in developing countries make clear, if automobile use is restricted, if buses are permitted to use more than one lane, and if off street loading facilities are provided, a single CBD street can accommodate more than 1,000 buses per hour. In contrast, the projected capacity of the proposed Main Street Bus Mall in Houston is 410-480 buses per hour (in two directions), depending on how fares are collected (Morris-Aubry Associates 1980, p. 15). The projected capacity of the proposed Main Street Mall only achieves these levels because automobiles and trucks would be prohibited from using it. It is evident from the data for developing countries, however, that mall design; the number, location, and design of stops; the number and timing of signalized intersections; and various policies combine to make the "capacity" of this six-lane (two-directions) street much less than its theoretical maximum capacity.

Table 11–4. Reported Volumes of Buses Per Hour for Surface Streets in Selected Cities

Location	Buses Per Hour	Autos Per Hour	Comments
North America			
Madison Ave., New York, NY	200	NA	2 Diamond Lanes
State Street, Chicago, IL	180	0	Bus–Only Mall
5th Ave., Portland, OR	180	0	Bus–Only Mall; Platooning
Market St, San Francisco, CA	155	1,200	Buses Use Multiple Lanes
K Street NW, Washington, D.C.	130	1,300	General traffic lanes
Eglinton Ave., Toronto, Canada	80	1,200	General traffic lanes
Elm St., Dallas, TX	80	1,345	General traffic lanes
South America			
Av. Amazonas, Belo Horizonte, Brazil	1,077	NA	Off–line stops, 4 lanes
Av. Brasil, Porto Alegre, Brazil	330	NA	On–line stops; 1 lane; Platooning
Av. Emancipacion, Lima, Peru	365	0	On–line stops; 1 lane; Platooning
Asia			Standard and Minibuses.
Lion Rock Tunnel Rd., Hong Kong	350	0	On–line stops; 1 lane; High Capacity, Standard, & Minibuses.
Taksin Road, Bangkok, Thailand	758	0	On–line stops;, Multiple lanes; High Capacity, Standard, and Minibuses; and Platooning

Note: Figures are from actual peak hour observations on urban arterials under 1972–1978 conditions.

Sources: (1) National Transportation Research Board, Highway Capacity Manual.
(2) Transport and Road Research Laboratory (U.K.), Study of Bus Priority Systems for Less Developed Countries: Phase I Report, (May 1989).

Bus Stops and Lane Capacity

The purpose of most CBD bus trips is to drop off or pick up passengers. In most United States cities buses serving the CBD use a curb lane and board passengers at a curb-side bus stop. In such situations, bus capacity is not so much constrained by street width, as it is by the facilities for passenger boarding and unloading. Where curb-side bus stops are used and buses are not permitted to pass, the capacity of a CBD bus lane is determined principally by the number of passengers boarding at the most heavily used stop and the amount of time it takes the average bus to collect or discharge its passengers at this stop.

The use of off-street terminals or boarding bays dramatically increases CBD bus capacities and reduces the amount of street space required to accommodate a given number of buses. As we discussed in Chapter 3, the Port Authority Bus Terminal in New York City accommodates 730 buses during the peak hour in off-street berths. In contrast, the highest reported single lane street volume in North America with curb-side bus stops is 180 buses per hour on a single lane in Chicago's State Street Mall. Ottawa accommodates 180-200 buses per hour on each of two streets during the peak hour using one through lane and a curb lane for passengers to alight and board. As we discussed in Chapter 5, buses use only part of the curb lane in each

block; the rest is available to cars and trucks for parking and loading/unloading. While ultimate CBD bus capacity is determined by many factors, and particularly by the extent to which the bus system relies on off-street bus loading facilities, it nonetheless is the case that the capacity of available curb lanes are critical in many situations. The discussion that follows examines the determinants of the capacity of a single bus lane.

Having buses stop sharply reduces the number of buses that can use a single lane. Simulation analyses reported in the Highway Capacity Manual indicate that up to 1,400 buses per lane per hour can be accommodated on an exclusive bus-only roadway with uninterrupted flow and no stops (TRB, 1985, p. 12-10). If each bus must stop once for 2 minutes to allow passengers to alight and board, however, the same lane can accommodate only 30 buses per hour. While this simple example ignores bus clearance time, i.e. acceleration and deceleration, it makes clear that stops have a critical role in determining the capacity of a single bus lane.

The simplest and most common type of on-line bus berth (curb space sufficient to accommodate a single bus) is a curbside bus stop which can accommodate no more than one bus at a time. As we have noted above, the throughput, or number of buses that can use a single lane, depends principally on loading/unloading and clearance time at the heaviest stop. Determining bus stop capacity is fairly straightforward, but it depends on a number of critical assumptions. The key factors are: passenger service time, which depends on the number of boarding, alighting or interchanging passengers, fare collection practices, and door configurations; bus clearance time, which should include door opening and closing, as well as time for buses to safely enter and leave a stop unimpeded; and the structure of the traffic cycle patterns.* In Chapter 12 of the Highway Capacity Manual, these factors are combined into a single equation for determining the number of buses that can use a single on-street berth in one hour.**

While having buses stop off-line can dramatically increase the number of buses that can be accommodated by downtown streets, there are drawbacks to using off-line facilities. Foremost among them are higher costs and the difficulty of locating terminals within a short walking distance of the ultimate destination of most riders.*** The siting of CBD bus stops and terminal entails balancing the desires of riders to stop as near to their destinations as possible, with the need to maintain bus speeds and frequencies. Stops are seldom placed more than a couple blocks apart, to keep passenger walking distances short. If buses can pass one another, the further bus stops for any given line are apart, the more lines - and thus more buses - can be accommodated on any given street. The number of bus stops on a single block is limited, however, by available space and competing uses. The number may be as low as one, with the re-

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* In the Highway Capacity Manual (p. 12-22), bus berth capacity estimates are calculated with clearance times between buses of 10 and 15 seconds. Ten seconds is said to represent the "absolute minimum time spacing possible at a stop for conventional buses."

** Bus capacity is not proportional to the number of berths provided at each stop. There are decreasing returns to the number of berths because it is highly unlikely that passengers will distribute themselves equally among berths or that the buses will use each berth in an identical fashion. As we discuss in Chapter 12, however, bus stop and lane capacity can be greatly increased by the use of convoys, where buses and passengers are assigned to a predetermined berth at each stop and buses are properly sequenced before entering the lane. In addition, it is quite challenging to schedule bus service so that buses will use a multi-route stop with an uniform distribution across time. As a result, at any given stop, for stops with more than one berth (curb space for a single bus), the number of effective berths, for calculating capacity, is always less than the number of physical berths (TRB, 1985, p. 12-21).

*** As bus volumes increase it may be possible to have buses serve different parts of the CBD. A highly developed scheme of this kind was proposed by Kain, et.al. (1981) for the Singapore CBD.

mainder of the block used for on street parking, or go as high as the block can physically accommodate, given block length, berths per stop, and space requirements for buses to enter and leave the stop.*

Dwell Time

Reductions in the dwell time associated with loading/unloading a given number of passengers unambiguously increases the capacity of a bus lane. The number of buses per hour that can be accommodated by a given stop is determined, in large part, by bus dwell time at each berth, and the number of berths. The fairly extensive preceding discussion about the number of effective berths and berth capacity should not obscure the simple fact that the number of buses that can be accommodated by a single berth is ultimately determined by loading/unloading time per passenger. If there is one berth per stop, and dwell time is 60 seconds per bus, then an estimated 33 buses could use a stop per hour (TRB, 1989).** However if dwell time per bus can be cut to 30 seconds per bus, 50 buses can be served.

Dwell time is almost entirely determined by the time required for passengers to board/leave the bus. Loading/unloading times depend on many factors, but principally on the type and design of buses used and the method of fare collection. Bus dwell time can be reduced by increasing the size and number of a bus' doors and by switching from payment upon boarding to payment upon exiting. As the data in Table 11-5 indicate, changing the type of buses and the payment scheme can increase the bus capacity of a stop by up to 24 percent, assuming 10 passengers board at each stop, or by up to 45 percent for 15 passengers per stop. Dwell time and thus stop/lane capacity are obviously highly dependent on the fare system and bus design.

Capacity and Policy

As the preceding discussion makes clear, determining the bus capacity of a particular CBD requires a plethora of assumptions. When rail advocates claim that a city's central area does not have the street capacity to accommodate large increases in the number of buses, such claims should be viewed skeptically. The preceding discussion on the relationship of bus berths and dwell times to effective street capacity of buses is intended to illuminate the matrix of factors that go into determining capacity; virtually all of these factors are policy variables.

One reason that many studies find that CBD bus capacity will soon be exhausted is that they assume few changes in the regulations governing automobile operations. Changes in traffic regulations can have significant effects on the estimated bus capacity of a city's central area. Instead of attempting to determine the optimal bus capacity, studies frequently aim to determine

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* As noted above, effective capacity per stop is a decreasing function of the total number of berths. For a given number of routes and amount of curb space allocated to bus use, increasing the number of berths will ultimately lead to a reduction in street bus capacity as the decrease in the marginal number of effective berths offsets the marginal increase in line capacity from spreading out passengers among stops.

** For the sake of simplicity, this discussion will abstract away from questions of bus headway, green time per cycle, and cycle length. The figures presented here are taken from calculations using a 15 second clearance and a ratio of green cycle to cycle length of 0.5. These calculations and other topics are extensively covered in the Highway Capacity Manual, (TRB, 1985, Chapter 12, Section III).

Table 11–5. Bus Loading Dwell Times and Buses Per Hour for On–Line Bus Stops by Payment System and Number of Doors Per Bus

Categories	For 1 Passenger	For 10 Passengers	For 15 Passengers
Estimated Dwell Time (Seconds)			
Pay Upon Boarding			
1 Door (Front)	3.0	45	60
2 Doors (Front)	2.0	35	45
2 Doors (Front & Rear)	3.0	45	60
Pay Upon Alighting			
1 Door (Front)	2.0	35	45
2 Doors (Front)	1.2	27	33
2 Doors (Front & Rear)	1.2	27	33
Buses Per Hour			
Pay Upon Boarding			
1 Door (Front)		42	33
2 Doors (Front)		47	42
2 Doors (Front & Rear)		42	33
Pay Upon Alighting			
1 Door (Front)		47	42
2 Doors (Front)		52	48
2 Doors (Front & Rear)		52	48
Assumed Clearence Between Buses (Seconds)		15	15

Note: Assumptions include: (1) 0.50 green time to cycle length ratio, and (2) one effective on–line berth per on–line stop.

Source: Transportation Research Board (1985). "Highway Capacity Manual."

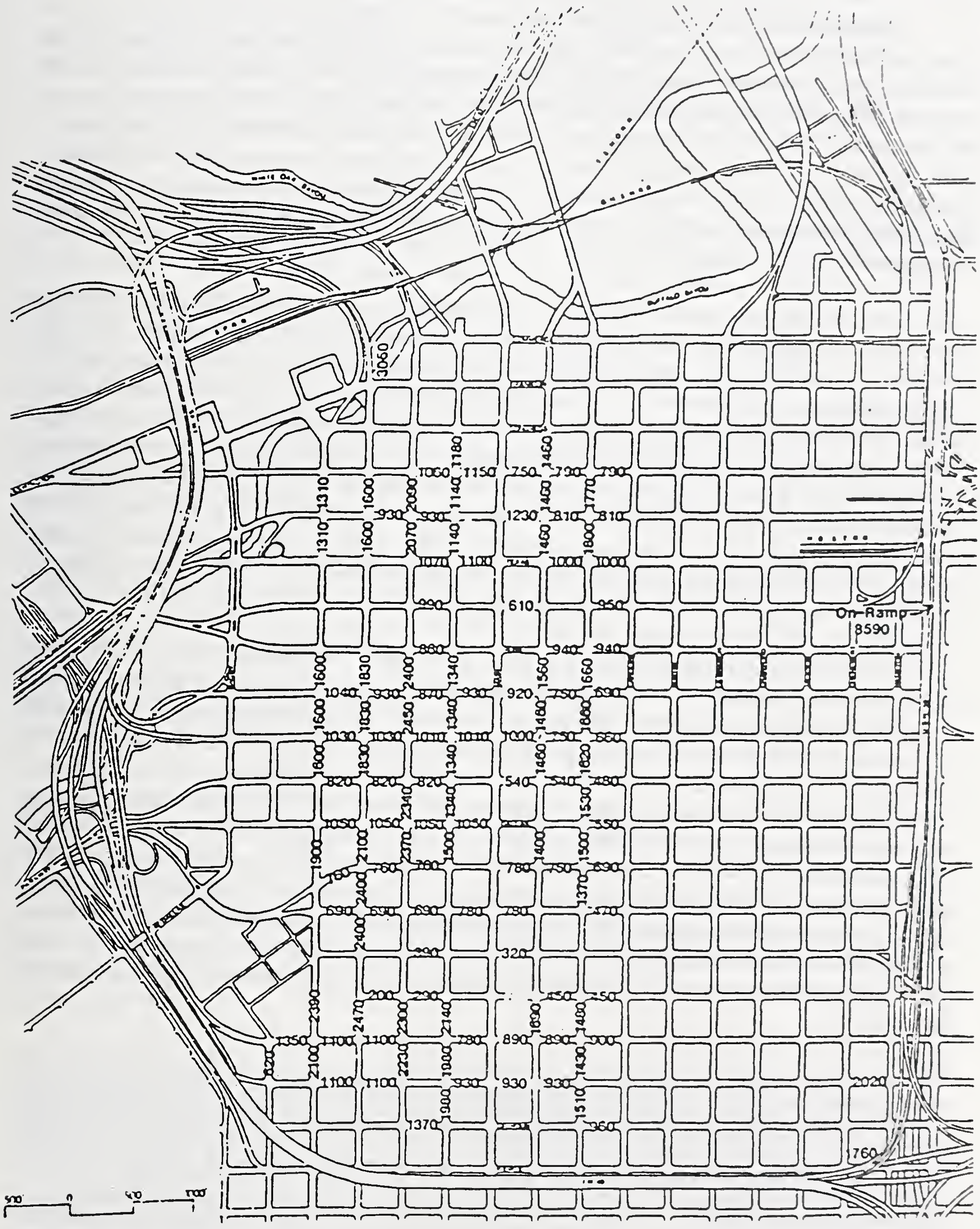
bus capacity on the assumption that no changes will be made in the rules and regulations governing auto use of CBD streets, and that there will be no or, at best, small changes in bus operations. The results of three separate studies that claim to "determine" CBD bus capacity in Houston, described below, illustrate these points.

CBD Bus Capacity Analysis: A Houston Case Study

Houston's CBD has a generous, perhaps even a lavish, amount of street space. As Figure 11-1 illustrates, Houston's downtown street system consists of a grid of one-way streets -- most are five lanes wide -- bisected in the north-south direction by two-way, six-lane Main Street. Most local bus services operate on Main Street and there have been proposals for a Main Street Transit Mall for more than a decade (Rice Center, 1978; METRO, 1980). The actual implementation of a Main Street Transit Mall has been held hostage to various rail proposals for the Houston CBD.

Barton-Aschman and Associates (1984) found that levels of service in the Houston CBD in 1984 were generally A, B, or C during peak hours. The only Houston CBD roadways which consistently operate at levels lower than C during peak periods are freeway ramps, including:

Figure 11-1. Houston Downtown Street System



the I-10 exit to Smith Street, the I-45 entrance from Pease, the I-45 (Gulf) entrance from Jefferson, and the US-59 entrance from Rusk. One reason that there is so little congestion on Houston's CBD streets is that the downtown has more street capacity than the streets, arterials, and other facilities that serve it.

The downtown grid is bounded in the north by Buffalo Bayou and on the other three sides by elevated freeways. The north, east, and west sides of the CBD have only limited street continuity to areas outside the CBD. Most access to the CBD is from the loop freeways and the capacity of these facilities and their ramps "produce a metering effect on inbound morning travel and encourage PM drivers to travel either earlier or later" (Barton-Aschman and Associates, 1984, p. 15). In addition, the CBD's modern high rise buildings all have extensive off-street loading facilities for delivery vehicles and are connected by an extensive network of skybridges and underground pedestrian tunnels, permitting those making foot trips within the CBD to avoid the oppressive summer weather.

The fact that the Houston CBD currently has little or no congestion, and is generously endowed with street space, has not prevented rail advocates from using the specter of CBD gridlock or the inability of the CBD streets to accommodate projected traffic as a justification for building expensive rail systems. As in Atlanta, Dallas, Singapore, or you name it, rail transit advocates in Houston have claimed for two decades or more that the city must build a rail rapid transit system because its central area street system will be unable to accommodate the large number of buses that are projected to use central area streets at some future date. Oddly, the critical date is always 10 to 20 years in the future, regardless of when during the past 20 or 30 years the study was done. These arguments have been used on several occasions to justify various rail transit proposals that have been advanced for Houston, usually in the context of evaluations of competing bus-rail and all-bus alternatives.

Voorhees and Associates (1973, p. I-23), for example, in its study of rail and busway alternatives completed for the City of Houston more than 15 years ago, found that "an all busway large system might appear to be most the attractive initially, but is considered inadequate as a long range solution," because "such a busway system, by 1990 would be causing the number of peak buses entering the CBD to be well beyond the practical/desirable capacity of the downtown street system" (Voorhees, 1973). At another point they added that "the number of peak hour buses entering the CBD (1,000 - 1,500 in 1990 and beyond) is considered beyond the practical/desirable capacity of the downtown street system" (Ibid.). The Voorhees analysis is typical of CBD bus capacity studies that are designed to justify the construction of a rail system; such studies typically use grossly exaggerated projections of CBD employment and tripmaking to produce unrealistically large future bus demands, and make no effort to change the nature of CBD bus operations to increase their efficiency and reduce the amounts of CBD street space they require.*

* Similar analyses were used by advocates of the Singapore METRO. They produced studies showing that "an all-bus system becomes operationally infeasible when Central Area employment reaches a total of somewhere between 260,000 and 290,000. ... The forecasted demand for Central Area employment and potential supply of non-residential floor space is such that Central Area employment will be higher than an all bus system can cope with .... For the traffic situation to be tenable along the north-south corridor in the late 1980s a mass rapid transit system would have to be provided. Road based transport facilities would be unable to cope" ("Report by the Committee to Study the Requirement of an MRT," (1976), cited in Kain, et.al., (1981)).

In their reevaluation of Singapore's MRT proposals, however, Kain, et.al. (1981) showed that existing CBD bus operations were incredibly wasteful of CBD street space and demonstrated that an improved, high-performance all-bus system could easily accommodate the levels of CBD employment projected for 1990, while reducing the number of CBD bus miles and improving

Barton-Aschman Associates, Inc. (1984, p. iii), in a study completed a decade after the release of the Voorhees study, similarly refer to the large numbers of buses that would have to be accommodated by CBD streets in the future, if an all-busway alternative was chosen:

> By the year 2000, it is expected that about 294,000 persons will work in downtown Houston. The all-busway option, with 1,985 peak hour buses operating system-wide is projected to have about 1,000 of these buses entering the CBD during the peak hour. Of these about 960 would provide service between downtown and other areas and 20 to 40 would provide internal circulation. This compares with approximately 375 buses now operating in the CBD during peak hour.

The specter of 1,000 or more peak hour buses causing gridlock in the CBD is used in both the Voorhees and the Barton-Aschman studies to reject less expensive all-bus alternatives to proposed rail systems. In the Barton-Aschman (1984) study, however, the 1,000 bus figure appears as an upper rather than a lower bound estimate of the volume of buses that would be using CBD streets during the peak hour, and the 1,000 buses are predicted to appear in the CBD a decade later than was predicted in the Voorhees study. The authors of the Barton-Aschman (1984, p. 34-35) study also found that some fairly modest street and traffic engineering improvements would permit the Houston CBD accommodate the 1,000 peak hour CBD bus operations projected for the year 2000 with an all-bus system, albeit under less than ideal circumstances: "The all-busway alternative can be accommodated in downtown under the probable growth scenario at traffic conditions which would be 'not desirable', but not unacceptable."

The most recent study of the problems of accommodating large numbers of buses in Houston's CBD was completed in October 1989 by Wilbur Smith, et.al. (1989b). According to its authors, the study's principal objective was determining "the maximum acceptable number of buses which can be accommodated within the core area of the Houston CBD during the afternoon (PM) peak hour." The Wilbur Smith et.al. report adds that its "analysis was undertaken to analyze the impacts of future traffic and the available capacity of the CBD core roadways to accommodate an all bus transit system, in lieu of a proposed 'System Connector'" (Ibid.).

The report's description of the methods used for the analysis is fairly brief and it is thus somewhat difficult to fairly evaluate the study or its findings. Still, it is clear that the study did not consider changes in bus operating procedures that would have reduced the amount of street space required per bus. As we discussed in the previous section, the most promising of these would be a simple change in fare collection methods that would greatly reduce bus dwell times at CBD bus stops and CBD bus hours. Large reductions in bus dwell times and CBD bus hours could be accomplished by simply collecting fares outside, rather than inside, the CBD during the PM peak period.*

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bus operating speeds and performance. The MRT Authority's consultants, after a through analysis of the Kain et.al. (1981) proposals, grudgingly agreed that the proposed all-bus scheme could accommodate the overly optimistic projections of 1990 CBD employment and tripmaking, and that the "system would definitely provide more efficient operations in terms of bus requirements and operating costs" than existed at the time of the study (1981), but they then argued that the all-bus system would be unable to accommodate the much higher CBD employment and tripmaking levels projected for the year 2000 (Wilbur Smith and Associates, et.al., 1981). Kain, et.al. (1981) disagreed with the Wilbur Smith assessment, arguing that further improvements in the proposed all-bus system would enable it to accommodate even the unrealistically high levels of CBD employment and trip making projected for 2000.

Even with its limited and highly conservative approach to determining CBD capacity, the Wilbur Smith, et.al. (1989b, p. 6) study found that "total effective bus capacity for the CBD in the year 2000 is approximately 850 buses, considering no provisions for special restrictions or other improvements to capacity (emphasis added)."** The authors of the Wilbur Smith, et.al. study also completed what they describe as a "suppositional analysis" to determine how much CBD bus capacity could be increased by means of traffic engineering measures. They found that introducing what appear to be rather modest restrictions on turning movements would increase the bus capacity of the CBD network to 1,000 buses during the PM peak hour, a figure, which incidentally is about the same as the one obtained in the Barton-Aschman study of CBD bus operations. The authors of the study state:

> A suppositional analysis was performed to assess the improvements to bus capacity that specific, reasonable improvements were made in the CBD street network. A significant impedance to bus-lane operations exists on Milam Street due to a large volume of right turns at the approach to Walker Street. A similar, though less significant, impedance occurs on Louisiana Street at Texas Street. The through-and-left lane of the double left turns allowed on Travis at Walker and Capitol effectively reduces the capacity for through movements on Travis at those intersections. If these capacity-limiting restrictions were eliminated it was estimated that the capacity of the CBD network to accommodate bus operations would increase to 1,000 buses during the peak hour (Wilbur Smith, et.al., 1989b, p. 9)

The analysis once again assumed business as usual, in terms of CBD bus operations and, in particular, fare collection within the CBD. The authors of the Wilbur Smith, et.al. study are very explicit about the limited scope of their analysis. They make it clear that the CBD bus capacity figure they obtain, 1,000 buses per hour, is very much of a lower bound estimate of what could be achieved through fairly simple and cheap changes in bus operations and various traffic engineering measures that would facilitate bus operations:

> The scope of this technical memorandum does not address the potential optimization of signal timings and offsets for the intersections of this study. Preferential treatment and/or network traffic optimization may be obtained by establishing better progression on selected streets or by changing cycle splits to allocate more signal green time to one or more streets. Nor does this technical memorandum address such issues as curbside boarding/alighting capacities, street environment, or future bus routing or operational issues (emphasis

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* While the Wilbur Smith, et.al. report does not provide a very detailed discussion of the assumptions used in the analysis, it does indicate that it assumes "an average of 30 seconds dwell time for each CBD bus stop." This fact suggests that the analyst's assume business as usual in CBD bus operations, rather than attempting to suggest ways of reducing the amount of street space required per bus.

** The report does not define "effective bus capacity," but its authors offer the following observations about the concept they use:

> Effective bus capacity accounts for buses that may (be) loop routed through downtown, noting that loop routing results in the same bus being counted twice as it passes through the study area. The "actual" number of buses in downtown will be lower than the effective capacity because of the impact of loop routing (Ibid., p. 6.).

added). Several of these elements are intended to be addressed in succeeding tasks of the CBD Bus Operations Study. (Ibid., p. 9.)

Finally, the simulation model used by Wilbur Smith, et.al. for their analysis of CBD bus capacity assumed that, "operations of a bus in mixed downtown traffic flow is the equivalent of five automobiles" (Ibid., p. 3). This corresponds to the higher of the two bus-auto equivalency figures we use in estimating the share of CBD street capacity used by buses in Table 11-1, except for the fact that we multiply this figure by two. While it is impossible to adequately evaluate this assumption without more information on how the traffic simulation model used by the consultants actually works, it appears that the passenger car/bus equivalency factor used is highly conservative at best and again depends on the assumption that buses collect fares in the CBD and use only one door.* CBD bus capacity also depends on assumptions about the projected numbers of other vehicles using the CBD streets. These volumes, of course, depend on projected CBD employment levels, the number and cost of CBD parking spaces, and, perhaps most importantly, the travel mode split. None of these critical assumptions were described in the draft report we received, although they may be included in other technical memoranda.

Given the earlier projections of 1,000 or more buses per hour entering the CBD during peak periods, first in 1990 and then in the year 2000, and the recent estimates of a 1,000 bus CBD bus capacity, the most recent projections of the number of buses entering (leaving) Houston's CBD per hour during peak periods, shown in Table 11-6, are more than a little bit interesting. As these data reveal, METRO analysts currently project a year 2000 CBD bus demand for an all-bus system of fewer than 665 buses per hour. The headings "Best Bus," "AA-TSM," and "New-TSM" refer to alternative all-bus networks assessed in the recent reevaluation of METRO's Rail System Connector.

Table 11–6. Peak Period Buses Per Hour Entering the CBD

	Articulated Bus			Standard Bus			Minibus			Total		
Route	Best Bus	AA TSM	New TSM	Best Bus	AA TSM	New TSM	Best Bus	AA TSM	New TSM	Best Bus	AA TSM	New TSM
Park and Ride												
from South	76	98	105	55	36	36	0	NA	0	131	134	141
from North	69	121	134	86	43	39	0	NA	0	155	164	173
All	145	219	239	141	79	75	0	NA	0	286	298	314
Local and Limited												
from South	6	20	20	98	148	117	63	NA	45	167	168	182
from North	0	24	22	118	136	107	53	NA	36	171	160	165
All	6	44	42	216	284	224	116	NA	81	338	328	347
Total	151	263	281	357	363	299	116	NA	81	624	626	661

Source: Kain, John F. "Best Bus Final Report" (1989).

* As the Highway Capacity Manual makes clear, choosing the correct passenger car equivalency for urban buses is very much of an art. The manual also indicates that a figure of 1.5 would be more appropriate in situations of uninterrupted flow and that the correct estimate depends on the duration of stop (dwell time) and signal progression (TRB, 1985, p. 12-4).

Best Bus is the improved all-bus system devised by Kain as part of the Rail Research Project initiated by Robert C. Lanier (Kain, 1989). As the data in Table 11-6 indicate, the number of buses projected to enter Houston's CBD in 2000 for the Best Bus alternative is slightly less than the number projected for the TSM Alternative used in the Rail System Connector Alternatives Analysis, and it is significantly less than the number for an improved TSM alternative developed by METRO staff as a competitive response to Best Bus, even though Best Bus would have substantially more riders (Kain, 1989). In addition, nearly 20 percent of the Best Bus units are smaller and more maneuverable minibuses. The number of articulated buses entering the CBD during peak hours in year 2000, moreover, is only 60 percent as large in Best Bus as in AA-TSM, 151 versus the 263 Articulated buses projected for AA-TSM.*

Improving CBD Bus Operations

Kain (1989) completed limited analyses of ways to reduce the projected year 2000 capacity requirements of buses in Houston's CBD. He found that changes in METRO's fare collection methods would be the quickest and cheapest way to dramatically reduce the visual impact and "presence" of buses in the CBD and the amount of CBD street capacity they use. Changing the method of fare collection would be particularly easy to do for park and ride services, which are projected to account for nearly half of all buses entering and leaving the Houston CBD during peak periods in year 2000.

At the present time, users of METRO park and ride services during the PM peak board their buses in the CBD through a single door and pay when they board. If they were instead allowed to use all of the doors for boarding and to pay their fares when they leave, the amount of time park and ride buses would have to spend on downtown streets during peak hours would be dramatically reduced. The amount of street capacity used and the visual impacts of buses are roughly proportional to CBD bus hours.

METRO's park and ride services are almost ideally designed for fare collection outside of the downtown. They load passengers at a park and ride lot in the morning and leave them off at the same lot in the afternoon. If fares were collected at the park and ride lots in the morning and evening, possibly off vehicle, all of the doors could be used for unloading (morning) and loading (evening) passengers in the CBD. In this regard, if there is a genuine concern about the amounts of central area street capacity that is currently used by METRO buses, there is a strong argument for replacing the standard buses METRO currently uses for park and ride operations with units that have additional and wider doors.

The savings in CBD dwell time from collecting fares at the park and ride lots instead of in downtown, are substantial, but they depend on the bus type and design. Kain (1989) found, as is shown in Table 11-7, that simple and inexpensive changes in fare collection methods could reduce the time METRO standard park and ride buses spend on CBD streets during the evening peak period by between 6.5 and 17 percent.

* The TSM alternative that was developed by METRO staff (New-TSM) has about five percent more buses per hour entering the CBD than Best Bus or AA-TSM. New-TSM, which uses minibuses on some routes, employs fewer standard buses than AA-TSM, but even more articulated buses, 281 in New-TSM vs. 263 in AA-TSM. Best Bus uses only 151 articulated buses.

Table 11–7. Bus Hour Savings from Fare Collection at Park and Ride Lots

Vehicle Type	Doors	Seconds Per Rider CBD	Seconds Per Rider P&R	Savings Seconds Per Rider	CBD Boardings	Hours Saved	CBD Bus Hours	Percent Saved
Standard	1	2.8	2.0	0.8	13,102	2.91	45.0	6.5%
Standard	2	1.9	1.2	1.6	13,102	5.82	45.0	12.9%
Standard	4	NA	0.7	2.1	13,102	7.64	45.0	17.0%
Articulated	1	2.8	2.0	0.8	21,557	4.79	50.3	9.5%
Articulated	2	NA	1.2	1.6	21,557	9.58	50.3	19.0%
Articulated	3	NA	0.9	1.9	21,557	11.38	50.3	22.6%
Articulated	6	NA	0.5	2.3	21,557	13.77	50.3	27.4%

Note: Savings are calculated on passenger boardings.
Source: Kain, John F. "Best Bus Final Report" (1989).

The actual extent of time savings per passenger, per bus, and per hour will depend on the bus and system characteristics described in previous section: including, method of fare collection at the park and ride lot, the number and width of doors, and other design features. Kain's analysis indicates further that between 9.5 and 27.4 percent of the time that METRO articulated buses would otherwise spend on the downtown streets in year 2000 could be eliminated by such measures, see the lower panel of Table 11-7. *

The scope for reducing boarding times and the amount of time buses spend operating on CBD streets is somewhat less for local buses than for park and rides. Because there is much more frequent passenger boarding and alighting on local buses, devising a satisfactory way of collecting fares outside of the central area, so that buses could use all doors for loading and unloading passengers in the central area, would be more difficult for local buses than for park and ride services. Still, the MBTA in Boston has been collecting fares at the residential end of bus trips (passengers making inbound trips pay when they board and those making outbound trips pay when they get off) for at least 25 years. Even a brief visit to Europe, moreover, will reveal, that there exist comfortable buses that permit much more rapid boarding than those used in most American cities. The problems of collecting fares outside the central area should be less of a problem for limited express services, which closely resemble park and ride services in their mode of operation and average trip lengths.

Conclusion

The implication of the Houston example is that CBD bus capacity can usually be increased if that is a goal of policymakers. When it is not a goal, then not surprisingly bus transit

* In addition to the substantial reductions in CBD bus hours, providing for off-vehicle fare collection at the park and ride lots would significantly reduce bus hours and might result in substantial operating cost savings. Even taking into account the additional staff required to collect fares at the park and ride lots, it is likely that off-vehicle fare collection at park and ride lots would provide significant savings in total operating costs. While we have not done the needed analysis, there is a good chance that more and wider doors would pay for themselves through bus hours savings, even if adding more or wider doors caused some loss of seating.

may not be able meet future increases in demand. It is misleading to suggest, as many rail boosters have, that the bus capacity of the CBD is some immutable physical constraint that limits the potential of bus transit to meet future growth in transit demand and that rail transit is the only answer.

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Chapter 12. Low Capital Cost Approaches to Central Area Distribution

Introduction

Transit malls, exclusive bus lanes, and various traffic engineering measures appear to be the most cost-effective approaches to improving bus operating conditions and bus passenger convenience and comfort in American cities. Successful transit malls are currently operating in Portland, Minneapolis, Denver, Vancouver, Honolulu, and Philadelphia, and transit malls have been proposed, but not implemented, in several other cities, including Houston and Los Angeles.

Cities in less developed countries generally have much less street space and many more transit users than comparable sized cities in developed countries, and they often lack the resources for capital intensive improvements. As a result, transport planners, transport engineers and transit operators in these cities have become highly adept at accommodating large volumes of buses on urban streets. The experience of these cities, and particularly of Brazilian cities with segregated busways on arterial streets, can provide valuable lessons to North American cities, and may suggest better ways of accommodating buses in central areas, where the heaviest bus volumes occur. Thus, we briefly review the operation of Brazilian segregated busways. First, however, we consider the experience of North American cities with transit malls.

Transit Malls

At least seven North American cities, Minneapolis, Philadelphia, Portland, Vancouver, Chicago, Denver and Honolulu have implemented bus-only transit malls and at least three others, Buffalo, San Jose and Sacramento have implemented bus-LRT malls in conjunction with new at-grade light rail systems. The bus-only transit malls differ considerably in terms of their length, the number of lanes used for transit, the width of sidewalks and boarding areas, and the extent of facilities provided for pedestrians/transit users. Table 12-1 contains brief descriptions of the seven bus malls and of the costs of building them.*

Minneapolis's Nicollet Mall, which was opened in November 1967, is usually credited with being the first permanent pedestrian/transit mall built in a major North American city. Since we were unable to visit to Minneapolis to evaluate the mall as part of this study, our evaluation relies entirely on secondary sources. Gladstone Associates (1977, p. 6-41) described the Nicollet Mall as having achieved "national recognition for ... its award winning innovative design and for its role in reportedly maintaining and revitalizing a major downtown retailing and office district." Similarly, Edminster and Koffman (1979, p. 19), in an UMTA funded evaluation of it and two other malls, observe that "Nicollet Mall provides a very high level of amenities," and note that

* Time and dollar budgets were such that we could only visit three of the cities with operating transit malls as part of this study i.e. Portland, Vancouver, and Denver, and thus the discussion that follows emphasizes them. We also made a short visit to Honolulu on other business, but this was before mall operations began. Site visits were also made to Seattle to see the bus tunnel, which was still under construction, and to San Francisco, which gives considerable priority to buses and street cars on Market Street.

Table 12–1. Characteristics of Transit Malls in North American Cities
(All Dollar Figures are in Millions of 1989 Dollars)

City	Year	Total Cost	Cost Per Mile	Length (miles)	Blocks	Width (feet)
Minneapolis	1967	$17.2	$35.9	0.48	8	80
Vancouver	1973	$7.0	$12.3	0.57	6	100
Chicago	1975	$26.0	$34.7	0.75	9	80
Philadelphia	1975	$15.0	$15.0	1.00	12	60
Portland	1978	$24.9	$47.1	0.53	11	80
Denver	1982	$28.4	$28.4	1.00	14	80
Honolulu	1988	$6.9	$11.5	0.60	9	50–64

"major design innovations include a serpentine-shaped roadway, enclosed and heated bus shelters, and electric snow-melting mats imbedded in the widened sidewalks."

In discussing the impact of the Nicollet Mall on transit service, Edminster and Koffman (1979, p. 75) emphasize that the primary objective of the mall, which is located on Minneapolis's principal retailing street, was to improve the retail environment and that "improvement of bus services and operations is viewed as a fortunate side effect." In assessing actual and potential time savings, moreover, Edminster and Koffman (1979, p. 91) conclude that "the mall appears to offer time savings compared to operations on a street shared with general traffic, but somewhat less than offered by contraflow lanes." They add that "both on the mall and on the contraflow lanes, signal timing works to limit the realization of these potential savings. More frequent stops and a different ridership composition on the mall use up much of the potential time savings there."

Edminster and Koffman also found that, at the time of their study (1979), the Nicollet Mall was operating well below its physical capacity most of the time and that 97 buses were scheduled in the southbound direction on the mall in the PM peak (4-6 PM), while 156 buses were using a southbound contra-flow lane on Marquette Avenue (Ibid, p. 96). As we indicated in Chapter 2, the Nicollet Mall is currently used by over 369 bus trips per day in each direction. The mall cost $17.2 million to construct (1989 dollars) of which 70 percent was paid for by local property owners through a special benefit district; the district also paid 90 percent of the annual operating costs of the mall (Ibid, p. 96.).*

Philadelphia's Chestnut Street Transitway, which became operational in 1975, is a 12 block, mile long project, that, like the Nicollet Mall, serves the retail core. Most of the facility is a two-lane, two-way busway on a narrow (60 foot wide) right of way; of the six transit malls included in Table 12-1, only the mall in Honolulu has a narrower right-of-way. Before the mall was constructed, Chestnut Street was a one-way, eastbound street. Autos are banned from the mall except for one block where they are allowed to access parking lots. Taxis are permitted to use the mall at night and to use one block of the mall to serve a major hotel. Edminster and Koffman (1979, p. 24) add that the major design innovation was the construction of signalized mid-block

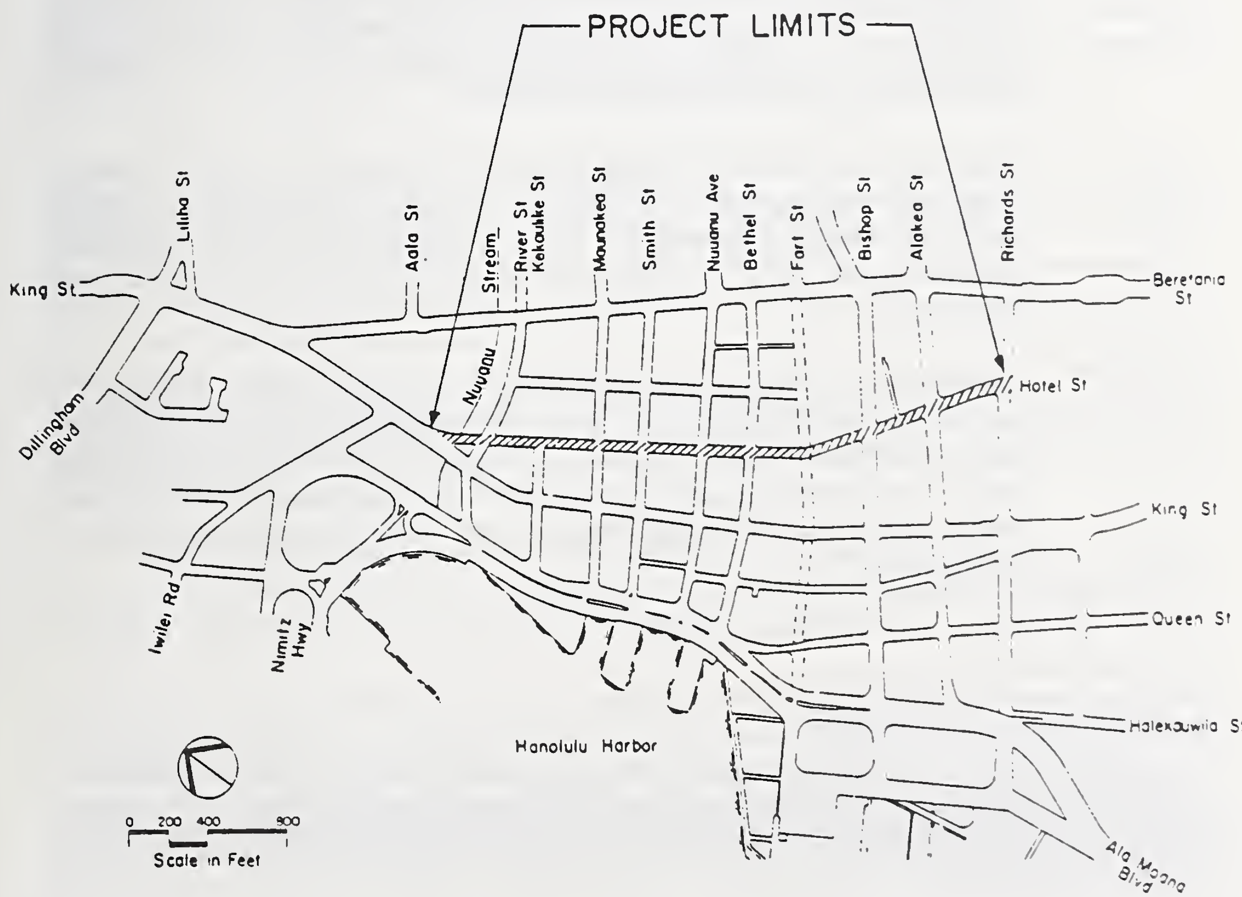
* Unless otherwise noted, all dollar figures are in 1989 dollars. Construction costs are adjusted to 1989 dollars using the ENR Construction Cost Index. All other costs are indexed using the GNP Implicit Price Deflator.

pedestrian crossings. An UMTA capital grant paid for 80 percent of the $15 million cost of the mall (1989 dollars), the commonwealth paid 17 percent, and the city only three percent.

The Honolulu Hotel Street Mall, completed in March 1988, is the newest of the six malls listed in Table 12-1. The permanent Hotel Street Mall, shown in Figure 12-1, replaced a "temporary" one-way, bus-only mall implemented in 1978. Hotel Street is quite narrow; the right of way is only 50-52 feet wide for most of its length, i.e. between River Street and Alakea street, before it widens to a (still narrow) 55-64 feet for the final block between Alakea Street and Richards Street.

Before the permanent two-way transit mall was built, Hotel Street functioned as a west-bound, one-way exclusive bus street. The highest volumes were obtained during the PM peak when about 100 buses/hour used the facility, a level Parsons Brinckerhoff et.al. (1985, p. 15) estimated was about 60 percent of Hotel Street's capacity operating as a one-way, bus only street. Slightly higher bus volumes occurred on King Street, the other half of the one-way pair, during the AM peak.

Figure 12-1. Honolulu's Hotel Street Transit Mall



The city's consultants recommended converting Hotel Street to a two-way, bus-only mall and using it for city buses. A demonstration project carried out in 1987 indicated that Hotel Street had a capacity of 95 - 100 buses per hour in each direction in two-way operation.* Since this is less than the number of buses entering downtown during peak hours, the consultants recommended assigning suburban and express buses to a one-way couplet, King Street (eastbound) and Beretania (westbound) between Aala Park and Richards Street** (Figure 12-1). The estimated construction cost of the Hotel Street Mall was $6.9 million in 1989 (Parsons Brinckerhoff, 1985, p. 61).

The Portland Transit Mall

Portland, Oregon may have the most successful transit mall currently operating in North America. The idea of a downtown transit mall was initiated in 1970 by a coalition of downtown business leaders and property owners. The proposed 5th and 6th Avenues transit mall, moreover, was a prominent part of the Portland Downtown Plan published in 1972 and was included as part of Portland's Federal Air Quality Standards, Transportation Control Strategy (1972). An UMTA funded feasibility study initiated in January 1973 provided further support for the mall concept and a mall design was completed in December 1975. Opened in 1978, Portland's 11 block $25 million (1989 dollars, the nominal cost in 1978 was $15 million) transit mall is unique in several respects. In contrast to most other transit malls in North America, the Portland Mall:

- Consists of <u>two</u> 80 foot wide parallel, one-way streets rather than a single two way street. Use of <u>two</u> one-way streets provides sufficient space for two bus lanes (a curb and a passing lane), for wide sidewalks and boarding areas, and a third, limited use access lane for other vehicles.

  Several benefits arise from the use of two parallel rather than a single two-way street; the most important are greater bus capacity and performance and a much less congested appearance. One-way operation means that <u>each</u> street must carry only half as many buses as when the street carries buses in both directions.

- Permits private cars and other vehicles to use a discontinuous third lane to access buildings along the mall. Since this "other vehicle" lane, is interrupted every fourth block, through vehicles are effectively discouraged from using the mall. A 1979 UMTA funded evaluation of the mall determined that "the general traffic lanes on the mall streets carry very little traffic" (Edminster and Koffman, 1979, p. 120).

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* The Hotel Street demonstration was carried out by the city in 1987 in an effort to prove the need for a heavy rail system that was being proposed for Honolulu at the time.

** The temporary one-way Hotel Street mall accommodated 114 westbound buses/hour before it was closed for reconstruction; the recommended routing assigned 57 westbound buses per hour to Hotel Street and 57 westbound buses per hour to Beretania Street. Before the two-way Hotel Street Mall was introduced, 118 eastbound buses per hour were carried by King Street; the recommended post-mall routing divides these eastbound AM peak hour trips between King Street (52 buses per hour) and Hotel Street (66 buses per hour).

- Was implemented principally to improve transit service and operates along predominantly office rather than retail streets. It crosses the principal retail street.

- Is the only North American transit mall that appears to provide clear-cut travel time savings for buses. The inclusion of a bus passing lane in the mall's design, Portland's unusually short downtown blocks, low before-mall bus speeds, and beneficial traffic signal settings appear to be the principal explanations.

The key to the Portland Mall's success is a generous allocation of CBD street space. As Figure 12-2 indicates, implementation of the mall entailed dedicating two of the 12 North-South streets serving the downtown to "nearly" exclusive transit use. Proposals to dedicate two CBD streets to nearly exclusive transit use would be strongly resisted in most cities because of the widespread perception that there is a need to provide more rather than less street space for autos. Observers in Seattle and elsewhere, moreover, are quick to point out that the Portland CBD is unusually well endowed with through streets and thus could more easily allocate two streets to transit use than other cities.*

Obtaining support for the proposed transit mall in Portland was apparently far from easy, however, and acceptance of the current design depended critically on UMTA's insistence that the mall be for the exclusive or "nearly" exclusive use of transit vehicles. Preliminary discussions with the business community led planners to quickly abandon an early two-lane proposal that would have provided two lanes for exclusive bus use on both 5th and 6th Avenues and no auto use whatsoever. Indeed, in early planning meetings, Portland businessmen, and particularly those fronting 5th and 6th Avenues, took the position "that any scheme that did not include at least two auto lanes was totally unacceptable" (Dueker, Pendleton, and Luder, 1982, p. 12).

Skidmore, Owings, and Merrill, design consultants for the mall, developed three alternatives with varying degrees of auto use. The first, a "3- 1/2 Lane Scheme," provided two exclusive bus lanes and a single auto lane with 8 foot wide pull outs for parking, loading, and dropping off. The second, a "3-Lane Scheme," provided 2 exclusive bus lanes and a single auto lane continuous between Burnside and Madison. The third, a "2- 1/2 Lane Scheme", provided two continuous exclusive transit lanes plus a third auto lane in all blocks except between Madison and Main, Yamhill and Washington, and Pine and Burnside." The project team and Transit Mall Review Board fairly quickly agreed that the 3-1/2 Lane Scheme would be too crowded and that the project should be sold on the basis that all parking and loading would be eliminated from 5th and 6th Avenues.

The city traffic engineer took the position that the final design should include a continuous third lane for future transit use. His justification was that a DeLeuw Cather (1973) study had determined that 260 buses per hour would be using the mall in 1990.** Interpolating between

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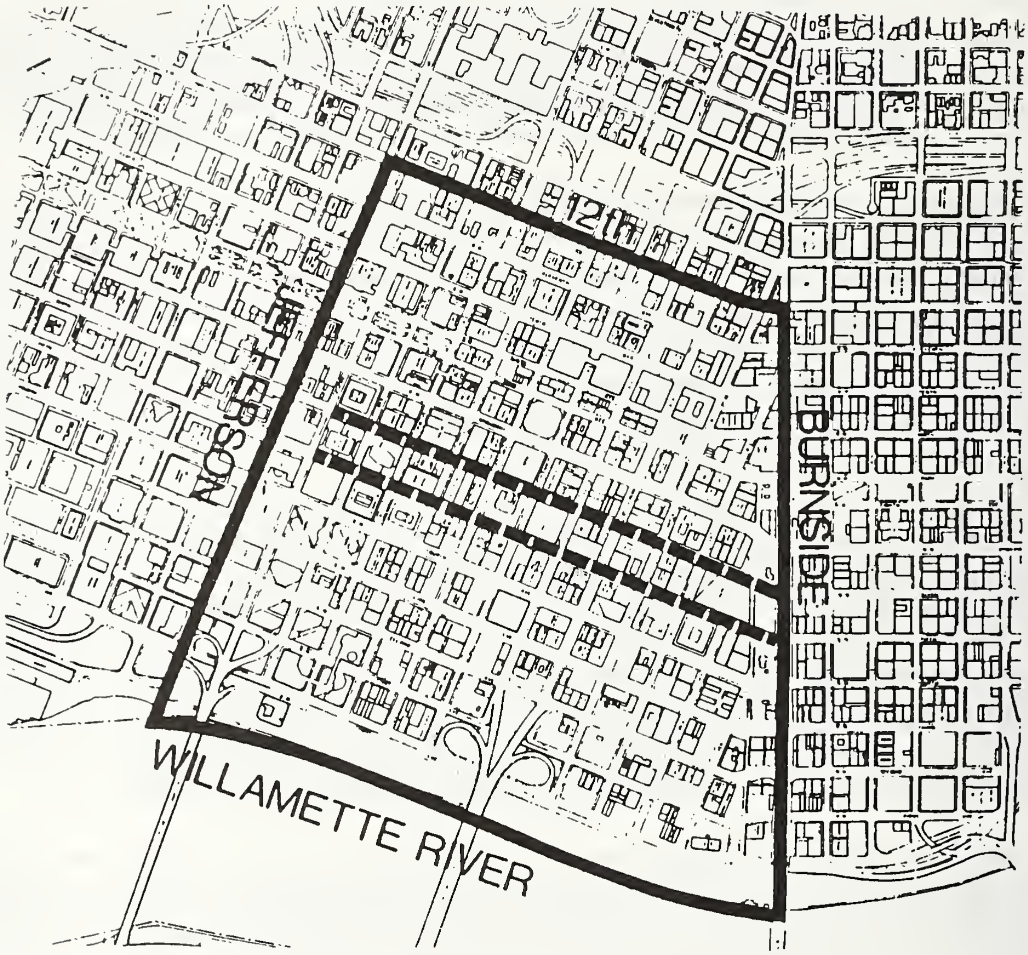
* The reason Seattle planners are so quick to make this point is to blunt criticisms of their decision to build a costly bus tunnel rather than follow Portland's lead and build a transit mall. Chapter 13 contains a detailed discussion of Seattle bus tunnel.

** The DeLeuw Cather (1973) projections assumed a fleet of a thousand buses, an all-bus system operating on radial routes oriented to downtown, and implementation of an extensive regional bus system with 22 miles of exclusive transit lanes in high volume corridors. The proposal included 160 miles of express routes, 22 miles of exclusive transit roadways and 15 miles of streets with reserved lanes. It also envisioned 13 major park and ride lots with parking places for 15,000 cars and an additional

Figure 12-2. Portland's Fifth and Sixth Street Transit Mall



the 1975 and 1990 DeLeuw Cather projections, the city traffic engineer concluded that all three lanes on the transit mall would be required for exclusive bus use by 1982. The DeLeuw Cather proposals for a high performance bus system received little or no support, as the region's transportation planners were already committed to the idea of completing a regional light rail system by 1990. For this reason, they anticipated that bus volumes on downtown streets would be much less in 1990 than the DeLeuw Cather report suggested. In their view, buses would be used primarily to feed the radial LRT system and provide cross-town service; most trips to downtown would be by LRT.

6000 spaces at some 30 express bus stops and community center stations; and recommended building an exclusive transit mall on 5th and 6th Avenues. The plan's cost was estimated at $513 million (1989 dollars); $186 million was to be spent on buses, $111 million for stations, and $126 million for transitways.

There was virtually no support for the idea of providing a third exclusive bus lane, both because a regional LRT system would make it unnecessary, and more importantly because it would have eliminated all "other vehicle" access, a notion that was viewed as being all but impossible to sell to the downtown business community, and particularly to those owning property on 5th and 6th Avenues. Downtown business interests continued to press for as much auto access to the mall as possible, and on May 31, 1973, the Downtown Plan Citizens' Advisory Committee unanimously endorsed the 3-Lane scheme with off-peak use of the transit lanes by taxis, airport limousines, and other commercial vehicles. Following a June 14, 1973 public hearing, where the business community, overwhelmingly supported the joint use of transit lanes by private autos, the Commissioner of Public Works filed a resolution for city council action specifying an operational plan and design based on the 3-Lane scheme.

In the proposed version of the 3-Lane scheme, the left lane would have been used by autos during all hours. The center lane, moreover, would have been available for auto use except during peak transit hours, until such time as buses required two lanes. The right lane would have been reserved for exclusive bus use, except when needed by police and fire vehicles, ambulances, and street and utility maintenance vehicles. Taxi and airport limousines would have been permitted to use the exclusive bus lanes when such use would not impede the efficient flow of mass transit vehicles.

On September 1, 1973 Tri-Met sent a preliminary grant application asking UMTA to contribute to the then estimated $31.6 million (1989 dollars) cost of designing and building the proposed 3-Lane mall. UMTA, in an informal response, indicated it would participate in the project only to the extent that the community was willing to commit 5th and 6th Avenues to mass transit. This was interpreted as meaning UMTA would fund only 45 percent of the total cost of the Council's adopted 3-Lane Scheme. UMTA's position caused prompt reconsideration of the "approved" three lane scheme. On January 3, 1974 the City Council reversed its position, and authorized the Commissioner of Public Works to negotiate with UMTA for maximum auto use on the mall consistent with maximum UMTA funding. At a January 16, 1974 meeting, UMTA officials agreed in principle that UMTA would participate fully in the project if the "2-1/2 Lane Scheme" with two full time exclusive bus lanes, running the full length of the mall, was implemented. Portland's City Council accepted the compromise.

Following difficult and time consuming negotiations relating to the environmental impact statement and access to the federal building by the federal courts and U.S. Postal Service, Tri-Met began to relocate utilities in October 1975 in advance of UMTA's agreement to fund the project.* On February 24, 1976 UMTA approved a capital grant of just under $29 million in 1989 dollars (the nominal amount was $15 million) for the project. While numerous problems and delays were encountered, the mall was completed in December 1977, on budget, and only one month beyond the initial targeted completion date.**

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* Tri-Met submitted a final grant application to UMTA on April 1, 1974 requesting UMTA's participation in the final design and engineering and construction cost of the proposed 2-1/2 Lane Transit Mall. UMTA provided a grant for design and engineering work, but refused to agree to fund the project's construction costs until engineering, final cost estimates and the Environmental Impact Statement had been completed.

** The preceding discussion of the design and construction of the Portland Mall draws heavily on, indeed frequently paraphrases and sometimes quotes verbatim from, a study by Dueker, Pendleton, and Luder (1982).

The mall was opened in early 1978. Unlike most other transit malls, the Portland Mall was conceived of and justified principally in terms of its effects on transit use. Project planners believed the mall would simplify the region's bus system, make it more understandable, and facilitate transfers. These objectives were achieved as nearly 90 percent of all downtown services were operating on the two mall streets in 1982. Most of the remaining non-mall routes crossed the mall on either Morrison or Yamhill Street.

It is difficult, if not impossible, to isolate the impact of the mall on bus ridership. Two years after the mall opened, the rapid increases in ridership achieved by Tri-Met during 1973-80 came to an abrupt halt as sharp fare increases, declining regional employment, falling gas prices, and the end of the gas lines caused ridership to trend slowly downward.* Finally, Tri-Met began operating its new 15 mile LRT line in September 1986. The new LRT, incidentally, does not operate on the mall; it crosses it at right angles. Proposals to have the LRT operate on the mall were rejected because of the cost and disruption that would have been imposed on the popular mall.

While the Portland experience may not be universally applicable because of the somewhat distinctive character of Portland's street system, with its short block and numerous through streets, the results of analyses of the mall's impact on CBD auto use and performance are nonetheless highly relevant. Richard Edminster and David Koffman in a 1979 evaluation of the Portland Mall found:

1. There is no evidence that the transit mall caused shoppers or other drivers to avoid the downtown area. Total vehicular movement into and out of downtown increased by nearly 10 percent between the pre-mall and post-mall counts.

2. Cordon count figures indicate that the Portland Mall has had only a slight impact on the routes chosen by automobiles to enter and leave the downtown area.

3. Traffic volumes within the downtown core, shown by the screen line counts, provide no evidence of an increase due to autos diverted from the mall streets.

4. The Portland Mall appears to have had no significant negative effects on downtown traffic conditions (Edminster and Koffman, 1979, pp. 119-21).

Edminster and Koffman (1979, pp. 124-5) reached similar conclusions about the impacts of the Minneapolis and Philadelphia transit malls, "there is no evidence that the restriction of auto traffic on transit malls caused motorists to avoid the downtown areas," and that "within the immediate vicinity of the transit malls, diverted traffic did not cause congestion on nearby streets."

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* Gas shortages, in particular, had caused Tri-Met ridership to reach abnormally high levels during 1980 and 1981.

The Denver Transit Mall

The Denver Transit Mall, shown in Figure 12-3, is, at once, a more radical, and a more limited, scheme than the Portland Mall. Denver's 16th Street Mall is a 14 block, one-mile long, two-lane (one lane in each direction) bus-only roadway, which connects express/regional bus terminals located at either end of the mall. The Market Street Station, located at the northwest end of the mall, serves 39 bus routes and the Civic Center Station, located at the southeast end, serves an additional 20 routes.

The Market Street Station has 10 bus bays, while the Civic Center Station with nine bays is slightly smaller. The layout of the Civic Street Station is shown in the top panel of Figure 12-4, while the Market Street Station is shown in the middle one. The bottom panel shows the mall itself. The total cost (including both land and construction costs) of the Market Street Station (opened in March 1983) was just under $16 million (1989 dollars), while the total cost of the Civic Center Station (opened in December 1984) was just under $29 million (1989 dollars); UMTA paid 80 percent of the cost of both stations. Construction cost for the mall itself was $28.1 million in 1989 dollars.

Before its conversion to a mall, 16th Street had an 80 foot right-of-way, with approximately 15-foot sidewalks, a parking/loading lane on the left hand side, three lanes of general traffic, and an exclusive bus lane on the right hand side. Since the mall in its final configuration has only two exclusive bus lanes (one in each direction) for its specially designed shuttle buses, creation of the 16th Street Mall eliminated three general traffic lanes on 16th Street and increased bus flows on 15th and 17th Streets, the parallel one-way pairs, somewhat.

While interest in a downtown mall existed a decade or so earlier in Denver, planning began in earnest in 1970, when Denver was selected as one of five medium-sized cities included in the UMTA funded Center City Transportation Project (CCPT). At the same time the CCPT was in progress, the possibility of a mall was being explored by the Denver Planning Office and Downtown Denver, Inc. (DDI). An initial feasibility study considered malls on 16th, 17th, and California Streets.

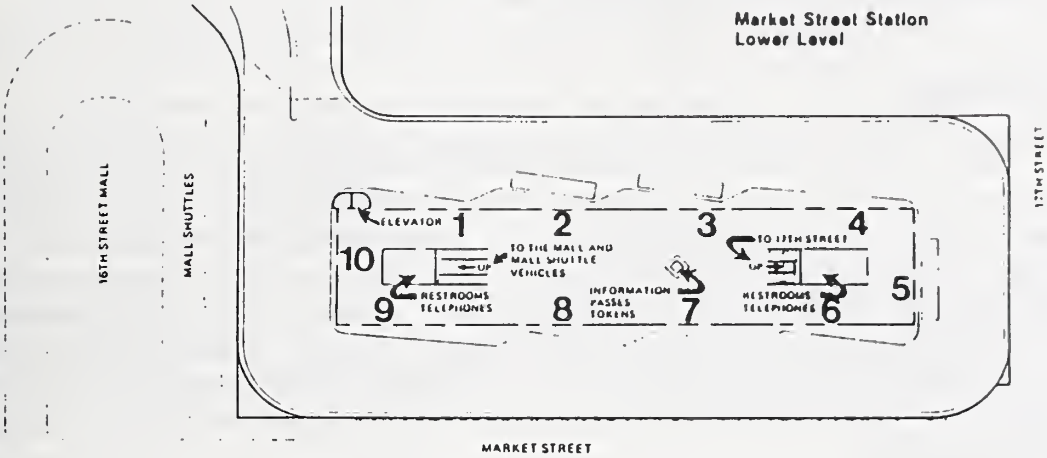
In May 1971, DDI's board approved the concept of a 16th Street Mall, and during 1972 board members arranged to visit Minneapolis to see the Nicollet Mall. A consulting firm was retained to study the effects of a mall on traffic conditions, and in January 1973, the Denver Planning Office and DDI published a pamphlet, "Downtown Denver Pedestrian Transit Mall Proposals," to promote the scheme. The pamphlet described two proposals: (1) a mall on 16th Street with a two-way transitway; and (2) malls on either 16th or 17th Street. A number of financial institutions and other large office occupants located on 17th Streets strongly opposed a 17th Street Mall and a consensus emerged for the 16th Street Mall.

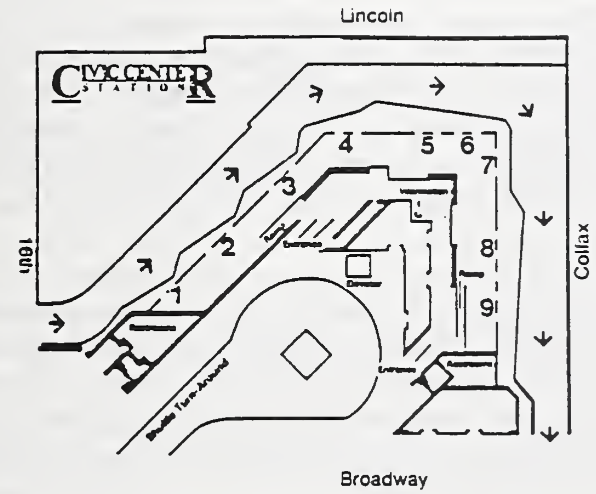
Efforts to implement a special assessment district to pay for the proposed mall failed, but DDI and city officials remained committed. The catalyst came in June 1976 when UMTA turned down RTD's application for funding to begin building a proposed light rail system, and urged RTD to develop a program of bus system improvements instead. With UMTA's encouragement, the city developed four mall schemes. All schemes called for re-routing express bus service to staging areas on the edge of downtown. In the four proposals, 16th Street was alternatively conceived of as (a) a pedestrian mall, (b) a transit mall with shuttles to serve the staging areas,

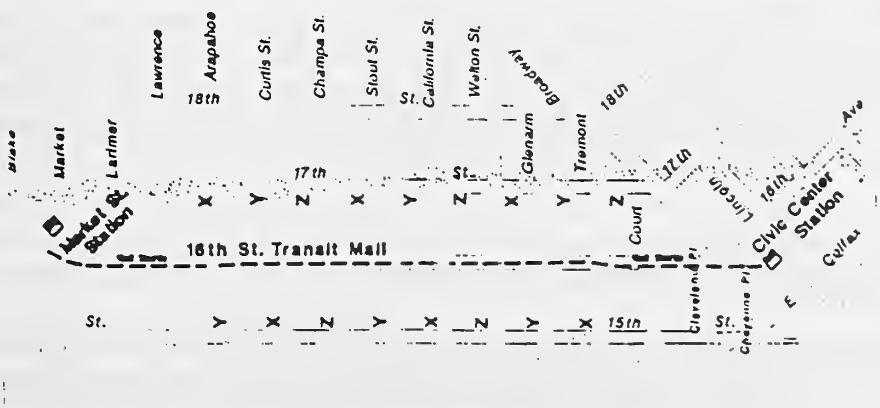
Figure 12-3. Denver's 16th Street Transit Mall

North

Figure 12-4. Denver's Market Street and Civic Center Stations







(c) a two-way exclusive bus street, and d) a pedestrian-only mall with an exclusive bus street on 17th Street. In November 1976, the DDI Board of Directors unanimously endorsed the shuttle mall alternative and RTD hired urban design and traffic engineering consultants to prepare a plan.* Mall operations began in March 1983.

Mall Operations

RTD analysts estimate that 69 percent of transit passengers using the Civic Center Station and 82 percent of those arriving at the Market Street Station transfer to (from) mall shuttle buses. A total of 160 bus trips arrive at the Civic Center Station between 6 and 9 AM each weekday; of these trips 93 (58 percent) arrive during the 7-8 AM peak hour. Express and regional bus routes serving the Market Center Station similarly produce a total of 120 arrivals during the morning peak period and 54 (45 percent) between 7 and 9 AM. During the morning peak, the Civic Center Station serves 4,250 persons and the Market Street Station 2,500. During the heaviest hour, (7-8 AM), 2,800 passengers arrive at the Civic Center Station and 1,350 at the Market Street Station.

Except for Denver, all other North American transit malls simply re-routed existing buses to their malls (typically a street heavily used by buses before the mall was implemented) and did **not** increase the amount of transferring required. Denver, however, allows only specially designed battery powered electric buses to use its transit mall and thus most express bus passengers entering and leaving the CBD must transfer to reach their final destinations. When the mall was being planned, there was considerable concern about the effect of these increased transfers on transit ridership. While there has been no formal analysis, RTD analysts and managers take the position that the impact has been negligible and is more than offset by other benefits.

The mall's capacity is limited by the size and design of mall vehicles.** With present equipment, RTD estimates the mall's capacity is 51 bus trips per hour (one bus during each 70 second light cycle). Since the vehicles now being used on the mall accommodate 60 persons, the mall's current capacity is about 3,000 persons per hour in each direction. RTD analysts feel there would be no problem in running two buses per cycle, a change that would double the mall's capacity. In addition, RTD is planning to acquire larger vehicles with four double doors that carry 120 persons each. When the larger vehicles have been acquired, the mall's capacity will be approximately 12,000 per hour in each direction.

Mall shuttle buses are free and operate 19 hours a day, 7 days a week. Frequencies are high except during the period 10:30 PM till closing (12:55 AM), when the shuttles operate on 30 minute headways. During the rest of the day, mall buses operate at 2 minute (6-9 AM, 11 AM - 1 PM and 4-6 PM), 4-6 minute (9-11 AM) and (6-10:30 PM), or 7 minute (5:45-6 AM) intervals. Most of the express/regional passengers using the mall stations who do not transfer to mall shuttles

* The preceding discussion of the development of the Denver Mall relies on material contained in Koffman and Edminster (August 1977, Chapter 9).

** Of the 26 buses commonly used for mall operations, six are powered by electric batteries and the remainder have been outfitted with equipment to minimize emissions and noise levels. The floors of the shuttles, moreover, are only eight inches above the curb; low floors, three extra-wide doors, and RTD's free fare policy for mall buses allows fast and easy boarding and unloading.

walk to destinations in the CBD; a smaller number walk to (from) bus stops within the CBD where they transfer to (from) local buses.

Off-peak use of the Market Street Station and ridership on mall buses is significant. While there is currently no off-peak (9 AM to 4 PM and 6 PM to 1 AM) use of the Civic Center Station, about 1,400 persons arrive at or depart from the Market Street Station during off-peak periods. Total off-peak use of the free mall shuttles actually exceeds peak period use; an estimated 22,000 persons use these vehicles between 9 AM and 4 PM on a typical weekday and additional 2,500 use them after 6 PM.

RTD analysts estimate that about 44,000 transit trips per day originate or end in downtown and that the 16th Street Mall reduced the number of buses operating on the downtown streets by nearly 600 trips per day and 300 during peak hours. Trips using regional and express routes, moreover, comprise about 39 percent (15,500 per day) of CBD oriented trips. The remainder of the transit trips originating in or ending in the CBD use one of the approximately 29 routes passing through downtown on other CBD streets. The larger part of these local buses operate on a pair of one-way streets (15th and 17th Streets) that parallel the 16th Street Transit Mall. The two other most heavily used CBD streets are a one-way pair (Champa and Stout Streets) that cross the mall.

We found the Denver Transit Mall somewhat of a disappointment, relative to the Portland Mall. Denver's 16th Street Mall appears to be working very well and takes a large number of buses off central area streets. Nonetheless, the mall's visual and physical environment are much less pleasing than the Portland Mall's. We believe design error is the principal explanation. While the treatment varies somewhat from one part of the mall to another, the architects designing Denver's 16th Street Mall created a wide median with trees, plantings, furniture and the like. In contrast to Portland, where the sidewalks were widened substantially, the sidewalks in Denver are not much, if any, wider than they were before the mall was built. The effect of these design decisions is to make the Denver Mall's sidewalks, bus stops, and pedestrian areas quite barren and much less appealing than Portland Mall's more spacious and tree shaded areas.* The Denver Mall's median also attracts pedestrians and thus encourages more pedestrian crossings of the narrow bus roadways than would have occurred if the activity centers had been located on sidewalks. Pedestrians crossing the roadway to and from the median are accidents waiting to happen.

In a few places, the wide central mall is replaced with a wide sidewalk - almost a plaza - on one side and this treatment seems to work better. In general, however, we suspect the Denver Mall would have been more successful if the additional space had been used for a smaller median and wider sidewalks. This design would have permitted the planting of trees on both sides, as in Portland, and would have produced a more attractive environment.

Another disadvantage of the Denver design, relative to the Portland one, is that it removes a much smaller fraction of buses from other central area streets. The transit mall serves only trips within downtown and suburban and regional express bus routes. Large numbers of local buses still operate on the parallel streets.

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* Climate differences and the fact that Portland's mall is eight years older than Denver's may be important considerations as well. Trees simply grow faster in Portland than in Denver, and Portland's trees have had more time to grow.

The Streets of San Francisco

San Francisco is one of the most densely populated cities in North America. On a typical weekday over 864,000 persons enter the San Francisco CBD and close to 130,000 enter the CBD by local transit. MUNI Metro and BART both operate in tunnels in the CBD and AC Transit uses bus-only ramps to reach its bus terminal on the edge of San Francisco's CBD. Even so, large numbers of diesel and trolley buses continue to use the surface streets to pick up and distribute passengers within downtown San Francisco. While the city has not built a transit mall, heavy bus use and center boarding platforms mean that Market Street, a two-way four-lane street on the south edge of the central business district, exhibits many of the characteristics of a transit mall and, in fact, is one, except in name.

Circa 1978 San Francisco's planners actually proposed creating a transit mall that would have excluded all traffic except buses and streetcars from Market Street Between 90 and 130 buses per hour loaded and unloaded passengers on Market between 1st and 3rd Streets during the morning and evening commute periods. These heavy volumes were causing serious congestion on Market St and were leading to "unacceptable" delays for transit users. When the Market Street Transit Mall proposal was strongly opposed by both Market Street merchants and by Mayor Feinstein, San Francisco's planners developed a compromise plan.

The compromise plan for Market Street allocated a much larger fraction of street space to transit, while at the same time allowing other vehicles to have continued access. The Market Street compromise, in this respect, resembles the Portland compromise, i.e. limited use of the mall by cars and trucks was to be allowed in return for an agreement to allocate nearly all of two Portland CBD streets for a transit mall. On Market Street, transit was given more street space by first extending the overhead trolley wires to all four lanes, and second, by making more extensive use of the passenger islands (stops) located in the middle of Market Street. These islands were originally built for the MUNI streetcars, which, as in many other downtowns, originally ran in the middle of the street until they were moved into the new MUNI tunnel.*

The use of all four lanes on Market Street provides more space for bus loading and unloading, and significantly reduces crowding and congestion at many Market Street bus stops. The Market Street transit scheme also results in a more rational allocation of bus stops. Buses with similar destinations are assigned to common loading and unloading points, i.e. in the eastbound direction buses stopping at the center-lane (island) are destined for the Ferry Building, while buses on curb-side lanes are headed for the Transbay Terminal.

Transit operations were also greatly enhanced by a decision to ban left lane turns by autos and trucks and by a re-timing of traffic signals to benefit transit vehicles. Turning restrictions, signal processors, and the use of all four lanes for transit loading and unloading have effectively discouraged most private motorists from using Market Street. As one transit official observed during our visit, "during the peak periods, the only cars on Market Street have out of state plates - people from the area know better."

* When the BART Market Street Tunnel was built, provision was made for MUNI's LRVs. BART currently shares two-level underground stations in the CBD with MUNI. BART operates on the lower level in its own tunnel, and MUNI Metro LRVs run in a tunnel on the level above.

The Market Street example illustrates the important point that traffic engineering measures other than total exclusion and the construction of full-scale transit malls can still significantly improve bus speeds and reliability in central business districts. Traffic engineering measures that re-allocate existing street space to the benefit of transit can have an important impact on transit operations and mode choices. In the next section, we examine experience with somewhat similar measures in Latin America.

Segregated Busways: Brazilian Style

Cities in North America might benefit greatly from examining the success of cities in Latin America and in other parts of the world in devising cost-effective ways of accommodating large volumes of buses on surface streets. Because of lower incomes, transit use in large and growing cities in developing countries is much greater than in comparable sized North American cities. This fact and limited funds for capital improvements have forced transport planners to devise ways of making more effective use of their more limited street space. This experience has broad application, but some of the schemes, particularly Brazil's arterial street, segregated busways, are particularly relevant to the problem of accommodating large volumes of buses in the CBD.

Latin American cities have made extensive use of arterial street reserved bus lanes. As in North America, both concurrent and contra-flow bus lanes have been implemented, and, as elsewhere the greatest success, has been achieved with contra-flow lanes, where the problems of keeping private cars from using the bus lanes and interfering with bus operations are less. Among Latin American cities, Sao Paulo has made the most extensive and most effective use of exclusive bus-lanes. By 1985, Sao Paulo had implemented 68.4 miles of exclusive bus lanes in 20 separate corridors (Scaringella, et.al., 1985). Sao Paulo's bus lanes produced time savings for bus commuters of up to 15 minutes per trip and significant reductions in bus operating costs. As we discussed in Chapter 11, these lanes accommodate large volumes; volumes in excess of 500 buses during the peak-hour have been reported for the Celso Garcia/Rangel Pestana corridor.

Sao Paulo's exclusive bus lanes worked very well for several years, but they have become less effective recently, as increases in car ownership and growing enforcement problems have combined to degrade their performance.* Sharp declines in the real value of fines for bus lane violations by motorists are an important part of the problem. Rampant inflation has reduced the real cost of traffic fines for bus lane violations to the point where their deterrent value has all but disappeared.

* Keeping private vehicles from reserved bus lanes is by no means easy. Since the curb lane is usually allocated to buses -- so that passengers can load and disembark from curbside bus stops -- there are frequent conflicts between buses and right turning private vehicles. Right turns, moreover, complicate enforcement and encourage violations by private vehicles by providing them with an excuse for being in the bus lanes. Finally, the operation of bus lanes is often adversely affected by frequent curb cuts for access to parking lots and buildings and by the need to provide pickup and delivery vehicles access to buildings.

Implementation of Segregated Busways

One solution to the problems of enforcing bus lanes is to physically segregate them. While this approach is not without its costs, including some operational disadvantages, it is nonetheless far cheaper than building a light or heavy rail line or even a grade-separated busway, and has proved highly effective.

In the last ten years, several Brazilian cities have implemented inexpensive and highly effective "segregated" busways in the center of arterial streets serving their central areas. While the designs of these facilities vary somewhat, the most common type, depicted in Figure 12-5, requires two traffic lanes and can be implemented in any arterial street with at least 75 feet (23 meters) of width. The busways, located in the center of the street, consist of a physically segregated exclusive bus lane in each direction and passenger platforms at approximately 0.4 mile intervals; passengers reach the busway at crosswalks.* Bus stops are staggered in the manner shown in Figure 12-5 to conserve precious street space.

Since segregated busways are only implemented when existing bus volumes are very high, there is generally no net reduction in the amount of road space provided other vehicles as a result of introducing the schemes, and in some cases the capacity of the general traffic lanes is actually increased. The drawings shown in Figure 12-5 are not from Brazil, incidentally; they illustrate proposals prepared by a team of British consultants for Bangkok. One of the British consultants had worked in Brazil and, inspired by the success of segregated busways there, recommended a similar scheme for Bangkok (HFA, 1985a and 1985b).

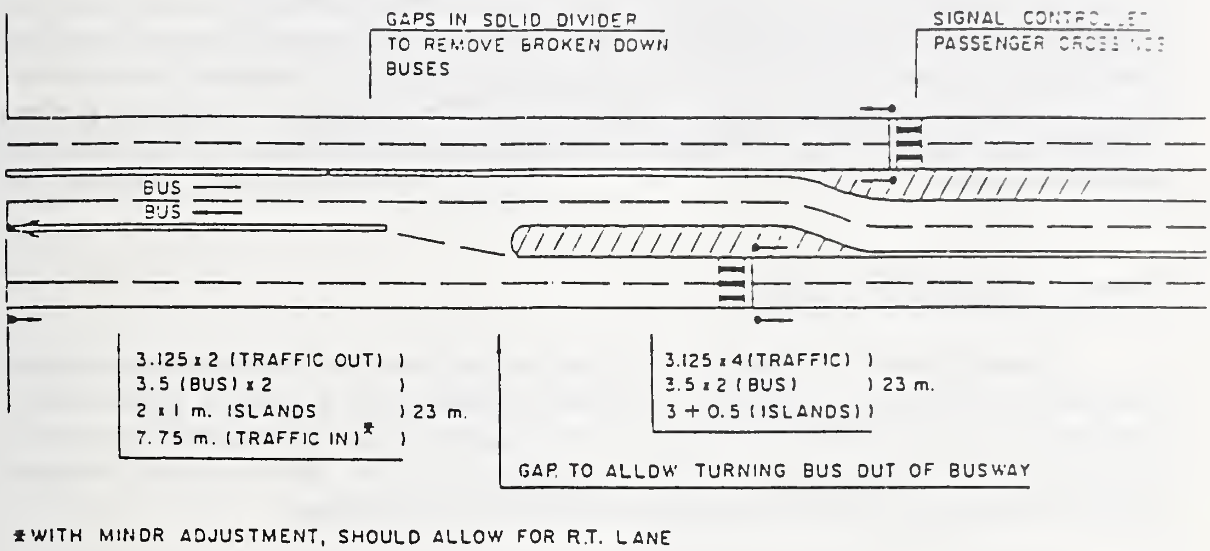
The incremental costs of building Brazil's segregated busways was about $858,000 dollars per mile in 1989 dollars (Armstrong-Wright, 1986, p. 72). Curitiba, Brazil is usually credited with implementing the first segregated busway in 1974, with financial and technical assistance from the World Bank and the Brazilian central government. The Curitiba system totals 33.4 miles and consists of five segregated busways linking as many corridors to the central area (Kain, 1990).

Volumes on Curitiba's five busways vary between 5,000 and 12,000 persons per hour in the peak hour/direction; the numbers of buses using the busways during the peak hour in the peak direction vary between 55, for the least heavily traveled West Axis, to 131, for the most heavily traveled South Axis. These volumes are actually somewhat lower than those reported for exclusive buslanes and segregated busways in Porto Alegre and Sao Paulo.

As we discuss in the previous chapter, the capacity of two-lane (one lane in each direction) segregated busways, such as those illustrated by Figure 12-5, depends principally on the time required to load and unload passengers at the most heavily used stops. The capacity and line haul speeds of two-lane segregated busways and of reserved bus lanes in Porto Alegre and Sao Paulo, however, have been dramatically increased by the use of the COMONOR system, i.e. bus convoys (Szasz and Germani, 1985; The World Bank, 1986; Thomson, circa 1985).

* Brazil's segregated busways located in the middle of wide arterial streets and with centrally located passenger waiting and loading/unloading areas in many respects resemble to arrangements provided for streetcars in many North American cities, where the street railways were the dominant provider of passenger transportation. When they replaced their streetcars with buses some cities may have allocated too much of the street space that had been used for transit to other users, and particularly in the central areas.

Figure 12-5. Typical Cross-Section of a Two-Lane Segregated Busway in a 75 foot Right-of-Way



Convoys are needed because buses using the narrow, one-way segregated busways cannot pass and the facilities are used by many different bus routes. In the COMONOR system a staging area is used to sequence the buses before they enter the busway with the order determined by the bus bays they are assigned to use at each stop on the busway. In Porto Alegre, which uses the COMONOR system, each bus stop can accommodate six buses at a time. Buses stop at the same relative position at each stop and passengers wait and board at these predetermined locations, greatly speeding the loading of buses and increasing busway capacity. Convoys also provide some speed and performance advantages at intersections, but the largest benefits result from savings in stop and boarding times at heavily used stops.

A recent World Bank study concludes that the COMONOR system can almost double the capacity of a two-lane busway in congested areas (Armstrong-Wright, 1986, p. 72). Using the COMONOR system, the Assis Brasil corridor in Porto Alegre currently achieves peak hour, peak direction passenger flows of more than 20,000 bus passengers on roughly 260 buses.* Forty different routes use the busway and services using the segregated facility average 11.8 miles per hour during the peak period including stops.

The Assis Brasil Segregated Busway is one of five such facilities currently operating in Porto Alegre. These five busways, which total 16.9 miles in length, carried a total of 776,000

* Alan Armstrong-Wright (1986) reports that one-way peak direction passenger volumes of 28,000 per hour have been achieved in the Assis Brasil corridor. Information obtained by Kain (1988) in Porto Alegre, however, indicates this figure may be somewhat high. Porto Alegre analysts put the figure at about 20,000 per hour. The discrepancy may be explained by the difference between the total number of passengers carried in the corridor in the peak direction, the number carried in both directions at the maximum load point, and the number of peak direction passengers at the maximum load point during the peak hour. Both of the first two measures, of course, be considerably larger than the third.

passengers per day in 1984. Reported bus volumes on the five busways in 1984 ranged from 46 buses per hour in the peak for the Cascatinha Busway to 270 buses per hour for the Farrapos busway (Motta Dos Santos, 1984). The number of individual lines using the facilities ranged from 9 for the Cascatinha Busway to 120 for the Farrapos Busway.

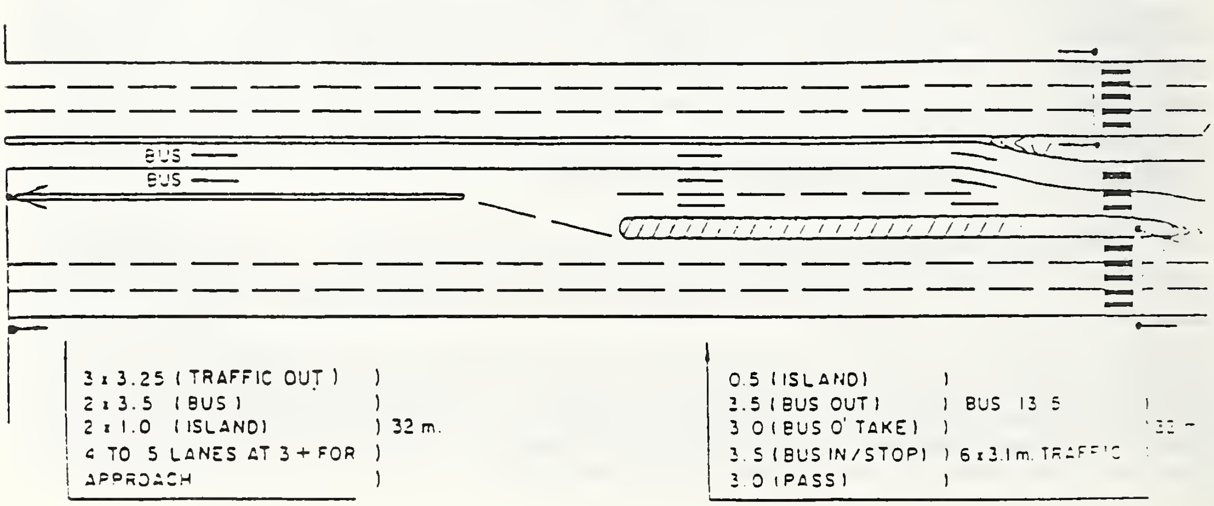
Capacity of the Assis Brasil Busway could be increased by the use of larger buses and by better organization of existing services, including possibly the development of a trunk and feeder network for the corridor. While a trunk and feeder system in combination with better designed and larger capacity buses could significantly increase busway capacity and perhaps reduce system costs, these modifications would require more transfers and thus should be carefully evaluated.

Three-Lane Segregated Busways

Substantially more capacity and a number of operational and performance advantages have been obtained from an innovative three-lane segregated busway recently implemented in Sao Paulo's 9 de Julho corridor. The 9 de Julho Segregated Busway replaced reserved bus lanes that worked very well for several years, until growing car ownership and increasing enforcement problems combined to seriously degrade bus performance.

As Figure 12-6 reveals, the design of the three-lane busway is similar to that of two-lane busways except that an additional "passing lane" is provided at each bus stop. The ability to pass means that the convoys are no longer necessary and a variety of express and limited stop services can be introduced. Express and limited stop services both increase system capacity and produce significant travel time savings for many riders. In addition, buses providing along the line service to all or part of the busway can pass buses waiting at bus stops if neither on-vehicle or waiting passengers request a stop. The 9 de Julho segregated busway is currently accommodating approximately <u>30,000</u> passengers in the peak hour, peak direction at the maximum load point without significant difficulty.

Figure 12-6. Typical Cross-Section of a Two-Lane Segregated Busway in a 105 foot Right-of-Way



Those involved in implementing the three-lane segregated busway in Sao Paulo argue that with some modest additional capital improvements, the 9 de Julho three-lane busway could come close to matching the capacity of a single-track metro. The 9 de Julho busway currently has two bottlenecks where narrow rights-of-way and intensive roadside development forced the busways designers to limit the facility to two lanes. While the required street widening and property acquisitions at these locations would be very expensive, the cost of these improvements would be a fraction of the cost of building an LRT or heavy rail transit system whose capacity would be no more and possibly less than the capacity of the current three-lane busway. These same analysts argue, moreover, that the door-to-door travel times of bus riders using the busways compare favorably to Metro door-to-door travel times, and particularly when express and limited stop services can be widely used.

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Chapter 13. Capital Intensive Approaches to Central Area Distribution

Introduction

A growing number of United States cities have implemented capital intensive approaches to the problems of reducing the presence of buses on downtown streets and improving downtown distribution for both commuters and persons wishing to make intra-central business district (CBD) trips. This chapter examines the recent experience with CBD bus tunnels and downtown people movers. While we refer to downtown bus tunnels and downtown people movers as "capital intensive" approaches to downtown distribution, it should be emphasized that total system costs for an all-bus system using either a downtown bus tunnel or downtown people mover for downtown distribution are likely to be much less than the total system cost of comparable light or heavy rail systems, which are often justified primarily in terms of their beneficial effect on downtown.

While there are relatively few examples of bus tunnels, a few exist. A bus tunnel operated in Harvard Square (in Cambridge, Massachusetts) from 1912 to 1975, and a new bus tunnel/station was built as part of the renovated Harvard Square Station, which opened in 1978. Seattle recently completed a 1.3 mile CBD bus tunnel and Ottawa is planning to build a bus tunnel as a CBD link for its innovative exclusive busway system. Although the Seattle tunnel was justified as a bus tunnel, provisions were made to convert it to rail, and it looks increasingly like a Trojan Horse. The completion of Seattle's bus tunnel is already being used by rail enthusiasts as a justification for implementing a LRT system. They argue that since a downtown subway is the most expensive part of a LRT system with grade-separation in the central area, it makes sense to use the recently completed bus tunnel as the core of a regional LRT system.* Seattle's "bus tunnel" was equipped with rails before it was opened.

Elevated downtown people movers are often suggested as "medium" capital cost, and relatively unobtrusive ways to augment scarce central business district space, to reduce the number of buses on downtown streets, and to improve circulation within downtowns. Downtown people movers have begun operations in Detroit and Miami, and we briefly discuss their experience in the final section of this chapter.

CBD Bus Tunnels

Bus tunnels are hardly a new idea. As we mentioned in the introduction to this chapter, Harvard Square was served by a half mile long bus tunnel from 1912 until 1975, when reconstruction of the Harvard Square Station, occasioned by the extension of the Red Line subway to Alewife Brook Parkway, forced the Massachusetts Bay Transit Authority (MBTA) to temporarily

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* A January 1989 Seattle Weekly story by Terry Tang describes a proposal for a four-year, $15.4 million Seattle Metro Study developed in response to a September 1988 directive from the METRO board to come up with a rail plan that would enable construction to begin by 1995 (emphasis added).

move its Harvard Square trolley bus operations to surface streets. A new bus tunnel was provided as part of the new Red Line Harvard Square Station.

The Harvard Square Tunnel, which was originally built for the use of streetcars, was subsequently converted to trolleybus use. MBTA officials long believed it would be impossible to operate diesel buses in the tunnel because of ventilation problems. However, the authority began operating some diesel buses in the tunnel a few years before starting construction on the new Harvard Square Station of the Red Line, in part, to assess the problems of operating diesel buses in the new tunnel.

Construction of the Red Line extension, and the associated reconstruction of the Harvard Square Station, made it necessary to close the Harvard Square trolley bus tunnel in 1975, at that point, the trolley bus operations were temporarily moved to the surface streets. When the new Harvard Square Station neared completion in 1978, nearly all Harvard Square surface buses, including both electric trolleys and diesel buses, were moved to a new two-level tunnel built as an integral part of the new Harvard Square station. The new bus and rail tunnels and stations are designed to enable transit users to make fast and convenient transfers between bus and rail without going outside.

At the present time about 49 buses per hour use the Harvard Square bus tunnel in each direction during peak periods, a level that is limited by demand rather than capacity. Peak hour and peak period boardings are not available, but it appears that about 4,125 inbound passengers per day currently use the nine bus routes that operate in the tunnel. This compares to about 4,350 persons per day in 1978, the year before the new tunnel opened.

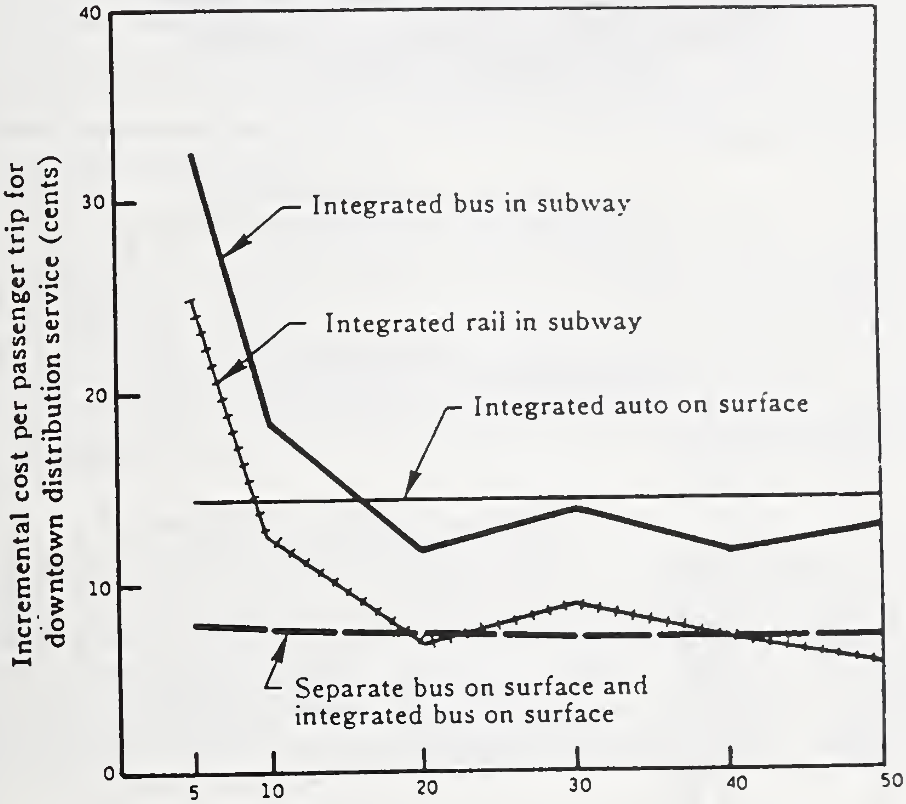
Inspired by the reality of the original Harvard Square Tunnel, Meyer, Kain and Wohl (1965) examined the feasibility and costs of bus subways for downtowns of various sizes. One of the five different types of downtown distribution systems included in their analysis was an integrated bus transit subway, where pairs of line-haul busways were extended in subways through the downtown area.*

Both downtown bus subway and bus station costs were based on rail costs; construction costs of downtown bus subway stations were increased proportionately to reflect the greater width required for bus stations, 128 feet for bus stations versus 50 feet for rail stations.** Meyer, Kain, and Wohl found a downtown bus subway would be more expensive to build and operate than a rail transit subway at every volume level; Figure 13-1 shows the comparative costs of downtown distribution for the five modes included in the analysis, assuming a two-mile

* As Figure 13-1 indicates, the other alternatives were: (1) integrated rail transit subway; (2) integrated bus transit on downtown streets (buses operating on pairs of line-haul busways using downtown surface streets for continuous, i.e. non-transfer trips; (3) separate feeder bus transit on downtown streets (as with the Denver Mall, this option assumed special downtown shuttle buses would take commuters from (to) downtown bus terminals or fringe parking lots to (from) their destinations (origins); (4) integrated automobile on surface streets (automobile travelers using surface streets to reach downtown destinations, or leave origins, directly from (or onto) the line-haul facilities).

** Meyer, Kain, and Wohl (1965, p. 285) estimated the annual cost of a 128 foot wide underground mezzanine-type bus tunnel would be $5,210 a linear foot (in 1989 dollars), and that a bus subway would entail additional ventilation costs over those included in the rail transit stations of $450,000 annually (1989 dollars) for each incoming line of each station. Connecting subway construction costs (to include an allowance for proper ventilation equipment) were assumed to be $40.6 million per line-mile (1989 dollars). All dollar figures, unless otherwise noted, are in 1989 dollars. Construction cost figures are converted into 1989 dollars using the ENR Construction Cost Index. All other costs are adjusted using the GNP Implicit Price Deflator.

Figure 13-1. Comparative Costs of Downtown Distribution Modes, 2-Mile Downtown Route Length (Costs are in 1965 Dollars)



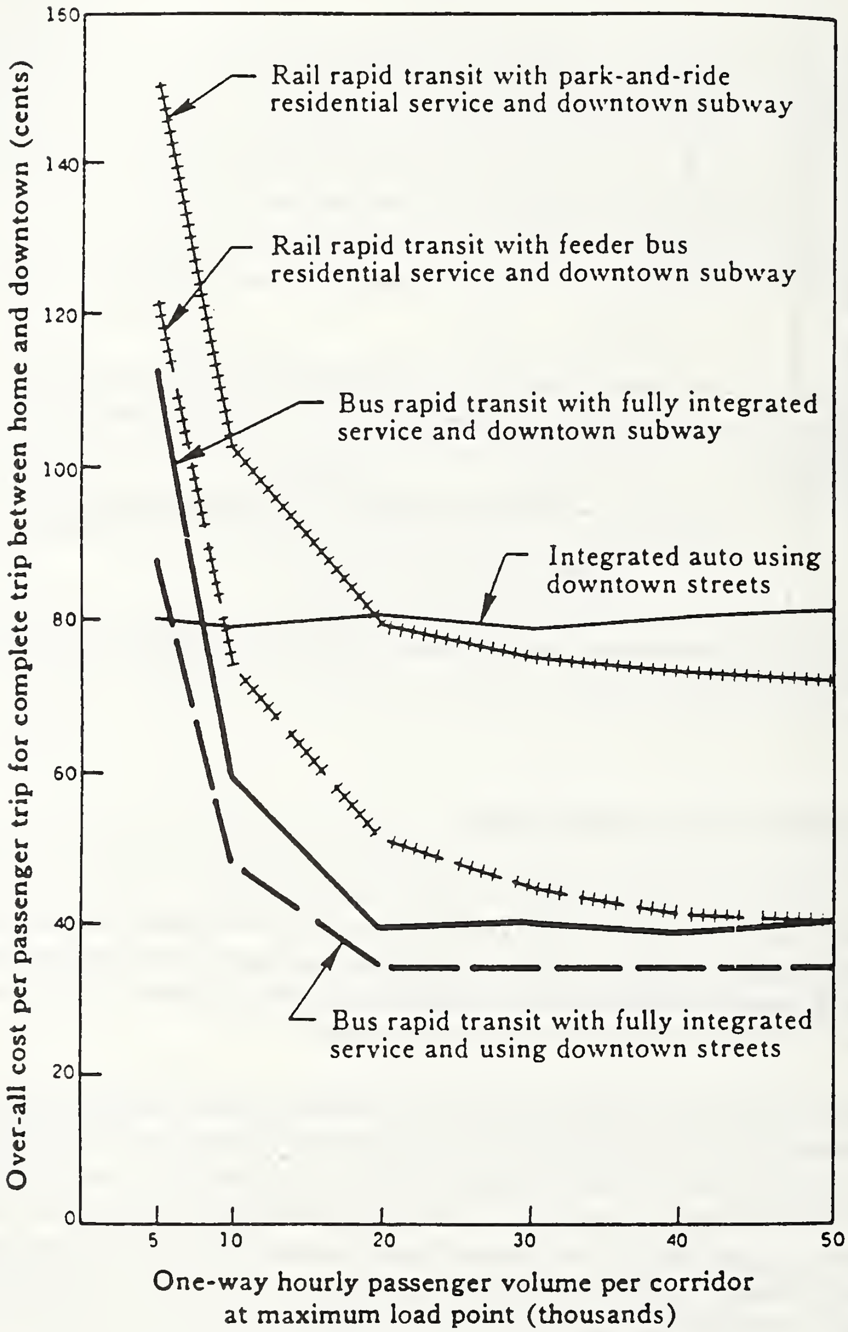
Source: Meyer, Kain, and Wohl (1965).

downtown route length. As Figure 13-2 illustrates, however, Meyer, Kain, and Wohl also found that total system costs (the cost of residential collection, line-haul, and downtown distribution) of bus rapid transit would generally be less than total rail transit system costs, even when an expensive bus subway was used for downtown distribution.

In spite of the Harvard Square tunnel and the Meyer, Kain, and Wohl analysis of bus tunnels, the possibility of actually building and operating a bus tunnel for distribution within downtown areas was largely ignored until recently. In the past few years, though, this has changed as Seattle recently completed a 1.3 bus tunnel for its all-bus system, and Ottawa is seriously considering a bus tunnel for its bus rapid transit system. We now consider Seattle's decision to build its bus tunnel in greater detail. Chapter 5 provides a detailed discussion of Ottawa's plan for a bus tunnel.

Figure 13-2.

Overall Home-Downtown Passenger Trip Costs for Medium Residential Density Along Corridor, Hourly Downtown Passenger-Trip Originations of Ten Per Block at the Home End, 10-Mile Line-Haul Facility, and 2-Mile Downtown Distribution System Route Length (Cost are In 1965 Dollars)



Source: Meyer, Kain, and Wohl (1965).

The Seattle Bus Tunnel

Seattle recently completed a 1.3 mile L-shaped tunnel under Third Avenue and Pine Streets in downtown Seattle. Seattle's decision to build a bus tunnel must be viewed as an exceedingly ambitious and costly effort to improve CBD bus operations and to reduce the number of buses operating on central business district streets. The project's "Final Environment Impact Statement" (Municipality of Seattle, 1985, pp. 1-5) poses the problem in the following way: "In 1980, over 490 diesel and electric buses were distributed over five downtown streets during the peak hour. The transit service required by 1990 (adding 140 buses to already congested streets and bus stops during the peak hours) would seriously aggravate transportation and environmental problems" (Ibid, p. 1-5).

As Figure 13-3 indicates, Seattle's Bus Tunnel will have five stations, three in the tunnel itself and one at each of the tunnel entrances (exits). Current plans are to restrict use of the tunnel to specially designed "dual-power diesel-electric" buses, although METRO could change this policy if its ongoing tests of methanol powered buses are successful. The tunnel is designed to allow eventual conversion to light rail; in fact, rails were added to the tunnel before it opened. METRO planners estimate 140 articulated buses per hour will be able to use the tunnel in each direction; a decision to operate wheel chair equipped buses in the tunnel significantly reduces its capacity.

METRO's decision to build a bus tunnel was made after completion of an UMTA sponsored analysis of the two tunnel and seven surface alternatives listed in Table 13-1. A number of significant common improvements were included in all of the alternatives, except "no-action." These common improvements included a busway connection to the two major interstate highways serving the Seattle CBD, I-5 and I-90 at the southern end of the CBD; an expanded surface, trolleybus circulation system for downtown; and an increased number of CBD by-pass bus routes.*

The Alternatives

The least costly of the seven alternatives, the so-called Transport System Management (TSM) Mall, was designed as a north-south, at-grade transit mall on Third Avenue. Third Avenue and Prefontaine Place South between Stewart Street and Fourth Avenue South would have been restricted to buses from 6 AM to 6 PM, Monday through Saturday (see Figure 13-3). This option would have maintained existing North-South contra-flow bus lanes on Second and Fourth Streets, and have added a new eastbound contra-flow lane on Stewart Street, 1-5 ramp modifications, parking restrictions, traffic signal adjustments, and a number of other TSM elements. The dual transit-only contra-flow lanes on Second and Fourth Avenues would operate 24 hours a

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* Washington DOT plans to construct a two-lane busway which could be converted to rail from the I-5/I-90 interchange to Airport Way South, south of the Seattle CBD. The State DOT also plans to build a busway on the existing Union Pacific Railroad right-of-way that will connect the Union Station with Spokane Street near I-5. The downtown circulation system, included with all alternatives, consists of new trolleybus routes, with overhead wires, power substations, and electric trolleybuses which would provide transit service within downtown. The METRO bus system currently includes over 25 CBD bypass routes, i.e. routes which do not pass through downtown, but which serve riders that might have to pass through downtown if these routes did not exist. Metro's 1990 Comprehensive Transit Plan and all of the alternatives would add additional bypass routes to the system.

Figure 13-3. Alignment of Seattle's Third Avenue and Pine Street Transit Tunnel

Table 13-1. Alternative CBD Distribution Schemes for Seattle
(Dollar Figures in Millions of 1989 Dollars)

				North-South 1990 Peak Hour Surface Buses diesel/total			1990 Ridership		
Alternative	Capital Costs	CBD Pk Hr Transit Capac.	Min. Saved Per Trip	Draft	Final	1990 Oper. Cost Savings	CBD Pkhr/ Pkdir	System wide (Millions)	Transfers
No Action	$0.0	25,000	0.0	477/630	521/642	$0.0	25,000	85.5	7,380
TSM									
TSM Mall	$42.5	31,000	3.3	477/630	521/642	$4.4	29,100	89.4	7,190
TSM Contraflow Lanes	$53.6	31,000	3.3	433/630	521/642	$4.4	29,100	89.4	7,520
TMS Non-Intercept Mall	$114.5	31,000	4.2	433/630	521/642	$4.3	29,300	89.7	7,350
Mall with Transit Centers									
Peripheral Terminals	$265.3	33,000	2.0	168/482	200/482	$4.3	27,300	85.9	19,360
Peripheral Stations	$265.2	31,000	3.3	178/538	210/538	$3.4	28,300	88.2	14,400
Close-in Terminals	$371.2	33,000	3.6	185/439	217/439	$4.6	28,400	87.8	14,160
Close-in Stations	$391.8	31,000	5.1	178/531	210/531	$3.7	29,100	89.2	11,490
Tunnel									
Third Avenue & Pine	$397.8	43,000	7.0	135/288	349/488	$5.0	30,100	90.6	8,100
Fourth Avenue & Pine	$282.6	43,000	7.0	135/288	349/470	$5.0	30,100	90.6	8,390
				Yr 2000	242/393				
				Yr 2000	242/393				
Source EIS	D&F	D&F	Final	Draft	Final	Final	Draft	Draft	Final

Note: Capacity figure same for Draft and Final EIS while number of buses differs significantly

day. They would be restricted to buses between 7 AM and 9 AM and between 3 PM and 6 PM; trucks would be permitted to use the lanes during other hours.

It appears neither the $42.5 million TSM Mall or the $53.6 million TSM contra-flow lanes option were considered by METRO as serious alternatives to its $397.8 million tunnel (all figures are in 1989 dollars). This is because METRO analysts simply decided that "both options pre-empt scarce street space without offering substantive urban amenities" (Ibid, p. 2-38). The $114.5 million Non-Intercept Mall (TSM) alternative (1989 dollars) appears to have been given somewhat more serious consideration, and was used as the TSM alternative UMTA requires for its alternatives analysis process. METRO analysts took the position that it was the "least expensive alternative which could be constructed entirely with local funds and still meet most of the project objectives" (Ibid, 1985, p. 2-39).

The Non-Intercept Mall (TSM) would have provided a bus-only, at-grade mall on Third Avenue and Pine Street (essentially the same alignment as the preferred tunnel alternative) and would have used the same costly dual-powered buses as are being purchased for use in the tunnel. Sidewalks on both streets would have been widened and Pine Street would have been converted from its current one-way, three lane configuration to two westbound and one east-

bound lane(s). Third Avenue would have been converted from a two-way, six-lane street to a two-way, four-lane street. The proposed I-90 busway would have been connected to the mall, providing direct access to the mall from the interstate highway system. In addition, the existing Pine Street bus-carpool ramp from I-5 would have been converted to a bus-only ramp.

Mall with Transit Centers consists of four distinct alternatives with capital costs in 1989 dollars ranging from $265.2 million to $391.8 million. All four alternatives used the same alignment as the Non-Intercept Mall (TSM) alternative, but added transit centers (stations or terminals) at either each end of the mall, as in Denver, or at intermediate locations.* The authors of the EIS felt that all four of the transit center alternatives had two principal advantages in comparison to the TSM Non-Intercept Mall option. Implementation of one of the four transit center alternatives would (a) remove between 104 and 203 buses from downtown streets in 1990 and, (b) approximately 300 fewer diesel buses would use the downtown streets in 1990, relative to the no-action alternative (Table 13-1).

All of the intercept mall alternatives would have required more transfers and would have been far more costly than the TSM Non-Intercept Mall alternative. The Final EIS (Ibid) indicates that the least costly of the intercept mall alternatives (the peripheral terminals and stations) would have cost $151 million more than the TSM Non-Intercept Mall and only $133 million less than the transit tunnel (all figures are in 1989 dollars). As we discuss elsewhere in this report, analysts in carrying out alternatives analyses frequently try to make the preferred alternative look better by "gold-plating" the less preferred ones. While we can not be certain that this practice was followed in the Seattle tunnel alternatives analysis, the capital costs of some of the surface alternatives, and particularly the Intercept Mall, seem high in comparison to the capital costs of transit malls built in other cities.

As with the tunnel alternatives, the dual-power vehicles included as part of the four Mall with Transit Centers alternatives would have operated as diesel buses on the regional highways before converting to electric trolley operation in downtown. In the two alternatives with stations at either end of the mall, the dual power vehicles would have entered the station by the same route as the diesel feeder-buses in the tunnel alternatives. After loading and unloading passengers, the buses would have passed through the station and travelled along the transit mall as electric trolleys, stopping at mall stops and at the station at the far end, before they changed to diesel operation and returned to the highway under diesel power.

In the two "Mall with Transit Centers - Close-in Terminals/Stations" schemes, the terminals/stations would have been at intermediate locations along the mall and regional buses would have used access tunnels to reach each terminal/station. The cost of these tunnels accounts for the much higher capital costs of these options. Dual power buses would operate as trolleys in the CBD and as diesel buses outside the CBD. As the last column in Table 13-1 indicates, fewer transit riders would have been required to transfer in the case of these two "close-in" alternatives than for the comparable schemes with peripheral terminals/stations, but somewhat more buses would operate on the mall and in the downtown.

* As the terms are used by METRO analysts, terminals are larger than stations and would be able accommodate (intercept) 150 diesel buses an hour; in comparison, stations would accommodate only 90 buses an hour and would require the use of dual-power vehicles as through-buses.

While most of the discussion included in the Final EIS deals with the difference between the preferred tunnel alternative and the "No Action" alternative, Chapter 7 of the Final EIS compares the preferred tunnel alternative to the TSM Non-Intercept Mall alternative, a scheme which closely resembles to the Mall currently operating in Portland, Oregon. The comparisons shown in Table 13-2 reveal that METRO's Third Avenue and Pine Tunnel, its "preferred" tunnel alternative, had a projected cost that was $259.4 million more than the TSM Non-Intercept Mall, but estimated operating and maintenance costs of $2.3 million a year more than the mall (all figures

Table 13–2. Comparisons of Benefits and Costs of the Seattle Transit Tunnel and the TSM Non–Intercept Mall (Dollar Figures are in 1989 Dollars)

Item	Tunnel	TSM Non–Intercept Mall	Difference
Total Costs for Tunnel (Millions of Dollars)			
Capital Cost	$371.8	$112.3	($259.4)
Surface Construction	$13.9		
Circulation System	$5.6		
Annualized Capital Cost	$37.8	$11.8	($26.0)
UMTA Annualized Capital Cost	$40.0	$11.8	($28.2)
Total O&M Costs Per Year	$181.0	$178.8	($2.3)
Value Time Savings Per Year			$18.6
Annual Ridership (Millions)	110.3	104.9	(5.4)
Work	63.4	60.3	(3.1)
Non–work	46.9	44.6	(2.3)
Daily Round Trips	385,664	366,783	(18,881)
Travel Time Savings Per Trip (min.)			3.9
Total Buses in CBD (1990)			
Total	642	488	(154)
Diesel	521	349	(172)
Value of Time Savings (Millions of Dollars)			$18.6
Cost per Added Daily Round Trip (Dollars)			
Total Capital Cost			$13,741
Annualized Capital Cost			$4.81
Capital Cost Per Bus Removed (Millions of Dollars)			
Total			$1.68
Diesel			$1.51
Net Quantified Benefits			
Total Per Year (Millions of Dollars)			($9.65)
Per Added Transit Trip (Dollars)			($1.79)

Note: Does not include $41 million extra for dual–mode buses. METRO includes surface and circulation costs under preferred, but not TSM alternative.

are in 1989 dollars). Combining the extra annualized capital costs of $28.2 million per year and the $2.3 million per year lower operating and maintenance costs indicates that the tunnel will cost $30.5 million per year more than a mall. The crucial question, of course, is whether this difference is worth it.

The principal projected benefits of the tunnel, enumerated in Table 13-2, are 3.9 minutes of travel time savings for each person using the tunnel, an additional 5.4 million riders per year (19,000 per day), and 154 fewer buses on Seattle's downtown streets during the peak hour in 1990. Total annual time savings in 1990 are estimated at $18.6 million per year (1989 dollars). In this analysis, as in many others, the benefits projected for the Seattle transit tunnel are highly dependent on projected ridership levels. Unfortunately, it appears that these ridership forecasts, as in many similar situations, are overly optimistic (Pickrell, 1989). METRO's decision to build its bus tunnel came just at the end of several years of successful efforts by METRO to increase transit ridership, achieved through a combination of aggressive service expansion and low fares.

In an August 1986 Seattle Weekly article, titled, "The Tunnel of No Return," published a month before construction began, Terry Tang observed that "critics of the Metro Transit Tunnel have often likened it to the WPPSS nuclear power plants which were born in an era when consumer demand looked like it would soar out of sight, but the need disappeared as the concrete got poured." She adds:

> The dismal short- and mid-term realities of stagnating bus ridership are overlooked because they can't be explained away.
>
> While the numbers that justified the tunnel fall apart, Metro administrators bravely tout instead some rosy picture two decades hence when workers pack onto buses and commuter demand is so high that Seattle will have to enter the big leagues by finally building its own light-rail system. Within a year the rationale for the tunnel has switched. Now the argument goes, even if the tunnel isn't necessary now or through the 1990's, its the first step to putting in trains. ...
>
> When the decision to build the tunnel was made in 1983, the scenario looked like this: Riders would increase by 33 percent between 1985 and 1990. Six hundred thousand bus-hours would have to be added to accommodate those passengers, and buses jammed in the downtown would come to a standstill. The picture for 2000 was even more horrifying. ...
>
> In the 1970's, when discussion of a tunnel as the ultimate solution to downtown's impending traffic jam began, demand for public transit seemed likely to skyrocket. Then, Metro's projections for the number of bus riders in 1990 was 138 million. That forecast almost immediately proved unrealistic. By 1985, the figure was whittled down to 87 million. This spring, Metro changed its 1990 estimate to 75 million. Similarly, projections for riders in 2000 have been chopped down. Last year, Metro staff predicted that ridership in 2000 would be around 110 million; this year, that figure dropped to 97 million. ...
>
> These new forecasts are still very optimistic. Actual bus ridership has never made it past the peak of 66 million riders in 1980. Metro is expecting only

63 million riders for 1986. Yet the agency is now counting on a 2.6 percent growth in riders every year from now until 2000 (Tang, 1986).

Downtown People Movers

Downtown people movers (DPM) have long been suggested as a cost-effective means of providing downtown distribution for radially oriented bus transit systems and for improving access within downtowns. Planners and policy makers have been attracted to the concept of automated, and usually elevated, people movers as a lower-cost alternative to unaffordable heavy rail systems. They hope these systems will be able to perform many of the functions of more costly rail systems, such as removing large numbers of buses from CBD streets during peak hours, providing convenient service to downtown workplaces for peak hour commuters, and improving the connections among downtown locations for off-peak users.

Interest in people movers in the United States emerged circa 1960 when several simple and relatively small automated people movers began operations in airports and other compact activity centers in the U.S., including the Dallas-Fort Worth and Fulton County (Atlanta) Airports, the Seattle World Fair, and Disneyland. The precise appeal of these technologies is difficult to explain, but a fascination with technology and the "high tech" image that came to be associated with them are important considerations. Potential savings in labor and operating costs are usually cited as advantages of automated people movers as well, but the support for them obviously has deeper and more elemental roots.

Responding to a growing interest in these technologies and increased demands to do something to revitalize downtowns, Congress, in 1976, provided Federal funding for an UMTA administered demonstration program to test the people mover concept. UMTA's DPM program was to pay up to 80 percent of capital costs of automated guideway downtown people mover projects in selected major urban areas as well as provide substantial grants for planning, technological assessments, and evaluations.

The DPM demonstrations had two stated objectives. The first was to test the performance of automated guideway transit (AGT) systems in urban environments.* The DPM projects were to be experimental in the sense of deploying advanced technologies in a new context, i.e. downtown activity center circulation. At the same time they were to use existing automated technologies, rather than new and untested ones. The second objective was to test the catalytic effects of "attractive and high quality" transit service in revitalizing some of the nation's depressed downtown districts or to assure continued growth in others.

Thirty-eight cities submitted formal proposals as candidate sites for a DPM system and six cities (Cleveland, Detroit, Houston, Los Angeles, Miami, and St. Paul) took part in the DPM Demonstration Program and its successor planning and implementing activities (Cambridge Systematics, 1988, p. 3-1). In December 1976, UMTA approved four cities, Los Angeles, Miami, Cleveland and Saint Paul, as demonstration sites for the DPM program. DPM system planning was stopped in Saint Paul due to a local referendum and in Los Angeles due to the withholding

* As of 1978, there was no urban experience available on the acceptability of automated, driverless urban transit operations, or on the environmental acceptability of elevated guideways of this kind in CBDs.

of funds by the Congress. The federal program was cancelled by the Reagan Administration in February, 1981. Even so, the UMTA demonstration program played an important role in the planning and implementation of DPM systems in both Detroit and Miami, although Detroit was not one of the four cities originally selected to participate in the program.

At the time this chapter was prepared, DPMs had been operating in Detroit for about 18 months and in Miami for a little more than a year. Even though experience with both systems is obviously fairly limited and, while it is much too early to expect much in the way of development impacts, the early experience of these two cities is nonetheless informative. Unfortunately, the experience to date in both cities provides little encouragement for those who expected downtown people movers to be the solution to downtown distribution and circulation problems.

Ridership on the Miami and Detroit DPMs has been disappointing. As the data in Table 13-3 indicate, system planners claimed that soon after they opened 41,000 persons per day would use the Detroit system and that 67,700 per day would use the Miami system. Actual ridership on the Miami system, however, has been only 26 percent of the projected level and actual

Table 13–3. Characteristics of the Miami and Detroit People Mover and Actual and Projected Costs and Ridership (Dollar Figures are in 1989 Dollars)

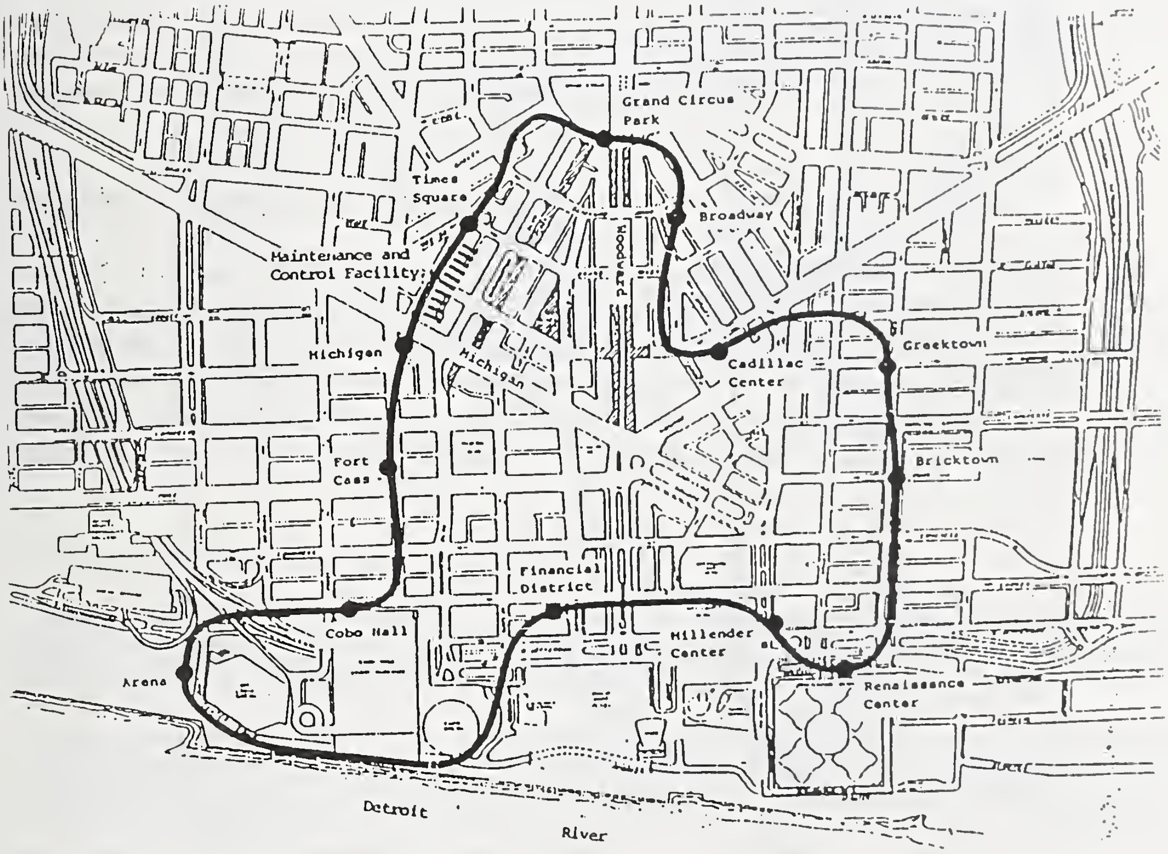
Item	Miami	Detroit
Year Service Began	1986	1986
Length (miles)	2.0	2.9
Number of Stations	9	13
Construction Cost (Millions of Dollars)		
Forecast	$86	$147
Actual	$178	$219
Percentage Difference	108%	49%
Percent Federal Govt.	53%	79%
Annual Operating Costs (Millions of Dollars)		
Forecast	$2.6	$7.7
Actual	$4.8	$11.4
Percentage Difference	84%	47%
Total Cost Per Rider (Dollars)		
Forecast	0.92	1.16
Actual	7.54	10.41
Percentage Difference	722%	796%
Weekday Boardings		
Forecast	41,000	67,700
Actual	10,800	11,300
Percentage Difference	–74%	–83%
Percent of Forecast	26%	16%

Source: Pickrell (1989), pp. 9, 15, 33, 41, 54.

ridership on the Detroit system only 17 percent of the projected level.*

The Detroit DPM consists of a 2.9 mile irregular loop depicted in Figure 13-4, and is one mile longer than the Miami DPM, which as Figure 13-5 indicates is a somewhat more regular 1.9 mile loop. The Detroit DPM has more than a third more stations, 13 as opposed to nine for the Miami DPM. Neither system was cheap on a per mile basis. The 1.9 mile Miami system, for example, cost $89 million per mile to build, while the longer, 2.9 mile, Detroit system cost $76 million per mile; both of these figures include the cost of acquiring vehicles and are in 1989 dollars.

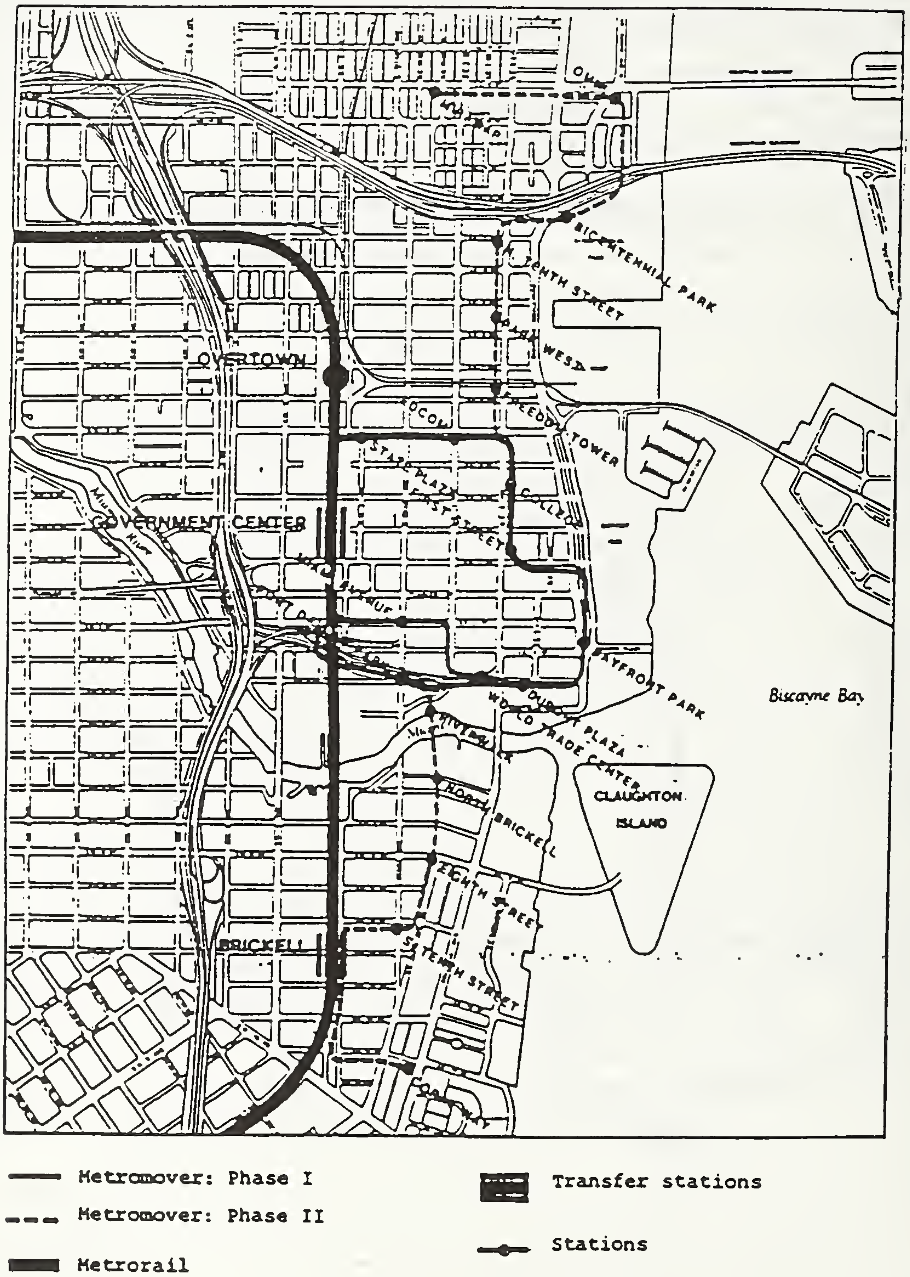
Figure 13-4. The Detroit CBD and Downtown People Mover Route



* The projection of 67,700 riders prepared in 1973 for the Detroit DPM was the first of four successively lower ridership projections for the system. The 1973 figure of 67,700 was revised downward to 55,000 in 1978, and to 35,000 in 1985, and finally to 16,500 just before the system opened (Mieczko, 1987).

Figure 13-5.

The Miami CBD and Downtown People Mover Route



As the data in Table 13-3 also indicate, the actual capital costs of both systems exceeded projected capital costs by a large amount.* In the case of the Miami system, the actual capital costs were 106 percent of those forecast; the cost overrun for the Detroit system was somewhat less, but actual costs still exceeded forecast costs by 50 percent.

Actual aggregate annual operating costs have also been significantly larger than projected operating costs, even with the much lower than projected ridership levels. According to Pickrell (1989), actual operating costs for the Miami DPM exceed forecast costs by 84 percent, the cost overrun for the Detroit system is 47 percent.** The large shortfall in ridership and serious underestimates of both capital and operating costs mean that actual total costs per rider are many times as great as projected. In the case of both the Detroit and Miami systems, actual total costs per ride are more than eight times projected cost per rider, $7.54 vs. $0.92 per ride in the case of the Miami system, and $10.41 vs. $1.16 per ride in the case of the Detroit system (all figures are in 1989 dollars).

There is no question that the performance of the DPM in both Detroit and Miami have been disappointing. The sections that follow provide a more detailed description of the Detroit and Miami's systems, as well as brief discussions of the problems encountered in planning and implementing them. We begin with a brief description of the Detroit DPM.

The Detroit Downtown People Mover

The Detroit DPM is an automated elevated guideway system connecting major activity centers located within the CBD.*** As Figure 13-3 indicates, the 12 DPM stations serve the financial district, Cobo Hall, the Renaissance Center, Joe Louis Arena, Cadillac Center (shopping mall), Greektown, Millender Center, Bricktown, Broadway, Times Square, Grand Circus Park, Michigan and Fort/Cass.**** The unmanned stations are equipped with security systems and special automated token machines. Station platforms have some localized heating, windscreens

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* An evaluation by Cambridge Systematics (1988, p. 3-14) concludes cost overruns for the Detroit system were largely caused by design changes and higher than expected land acquisition costs. Two stations were redesigned and the maintenance and control facility was relocated to accommodate development activity. In addition engineering inspections during the "final" stages of construction revealed major casting flaws in 18 percent of the concrete beams in the elevated structure.

** While the federal and state governments paid 99 percent of the capital cost of the Detroit People Mover, the city has had to pay the increasing operating cost shortfalls. A recent editorial in the Detroit News (1989) comments on the rising subsidy costs for the DPM and asks whether it is the best use of scarce city tax revenues. "Detroit Mayor Coleman Young has presented his proposed $1.89 billion budget to the City Council... Two items stand out ... First, if the mayor gets his way, the police department will take a $9.8 million cut and end next fiscal year with 264 fewer officers. Second, the subsidy to the Detroit People Mover will increase to $8.3 million - up $2.4 million from the current years subsidy of $5.9 million.

On these two points, we think the administrations priorities are out of line. Detroit's crime problem is at the core of much of the social and economic decline the city faces. Yet, the administration is willing to make a major investment in the People Mover, while making a disinvestment in a safe and secure environment for people and businesses. As long as crime is the life and death issue in Detroit, the City Council should find other places to cut. That includes the People Mover subsidy, if necessary."

*** This section draws extensively from descriptions contained in Cambridge Systematics Inc (1988).

**** The downtown area is 1.25 square miles, with the highest development density concentrated in the approximately 1/2 square mile surrounding the DPM Employment in the Detroit CBD totaled 105,000 in 1980; its residential population was only 5,300 in the same year.

and canopies.* The current fare is $.50 per trip.

The Detroit DPM currently uses 4-6 trains, depending on demand, to traverse the single loop at any one time. People mover trains, which can operate either individually or in pairs, have a capacity of 112 passengers and have steel wheels which run on steel rails. The trains require approximately 15 minutes to complete the entire loop at an average speed of 12 mph. While the system was designed to operate at two minute intervals during peak periods for a peak hour capacity of approximately 6,000 passengers, current peak period headways are just under three minutes. The Detroit DPM operates on Monday through Thursday 7 AM to 11 PM, Friday 7 AM to 12 PM, Saturday 9 AM to 12 PM, and Sunday 12 noon to 8 PM.

In the case of several DPM stations, joint development projects provided for the integration of stations into structures. For the most part, however, the system is located within street right-of-way using curb lanes and medians or runs through surface parking lots and on vacant land to minimize land takings and property acquisition costs. The maintenance, storage, and system control facility is located at the fringe of the CBD core; trains use a by-pass to access the facility from the main guideway.

Somewhat unexpectedly, most trips on Detroit's DPM occur during off peak periods and on weekends. Indeed, more than half (54 percent) of weekly ridership occurs during three days, Friday through Sunday, even though only eight hours of service are provided on Sundays. Saturdays, which account for 22 percent of total weekly riders, have the highest average daily ridership. In contrast, ridership on a typical weekday is only 10 to 12.5 percent of weekly ridership.

The Detroit DPM system is used most heavily when special events, particularly sporting events are held at the Cobo and Joe Louis Arenas. The highest monthly ridership to date occurred during March 1988 when there were 28 days of special events, concerts, conventions, and hockey games. Ridership is also somewhat higher during periods of inclement weather. The systems' heavy orientation towards social-recreation, rather than work trips, is reflected in the distribution of boardings by stations. More than one-fourth (28 percent) of boardings take place at Greektown Station, Detroit's ethnic entertainment and restaurant district (Pastor, 1988). The Renaissance Center, with 19 percent of total DPM boardings, is the second most heavily used station.

Planning for the Detroit DPM

Ever since a people mover was first proposed in a city sponsored "Central Business District Study" in 1969, revitalization and development plans for downtown have featured an automated downtown circulation system.** Soon after the release of the 1969 study, the Mayor

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* Because expected passenger waiting times at stations was to be one minute during peak hour and only slightly more at other times, more extensive heating and cooling of the stations were thought to be unwarranted.

** Detroit city and Carter administration federal officials hoped the Detroit people mover project would act as a major catalyst to revitalize the declining Detroit CBD and central city. The City of Detroit lost 28 percent of its population between 1960 and 1980 and the City's share of total metropolitan area population during the same two decades decreased from 43 percent to 23 percent. Similarly, between 1967 and 1984, retail sales in the CBD declined by more than 40 percent, with a corresponding decrease in the number of retail establishments and retail employees in the area (Cambridge Systematics Inc., 1988).

appointed a steering committee of business representatives and city officials to provide policy input and to ensure the resulting downtown circulation plan would command broad-based community support. Relying on forecasts of higher ridership, greater increases in commercial and development activity, lower operating costs, and an expected reduction in demand for parking in the CBD, relative to an all bus alternative, the steering committee selected a DPM as the locally preferred alternative (UMTA, 1980c).

When UMTA announced its Downtown People Mover Demonstration Program in 1976, the Southeastern Michigan Transportation Authority (SEMTA) had already completed an Environmental Assessment Report for a 2.3 mile DPM loop. SEMTA, therefore, submitted a project proposal to UMTA based on the 1975 EIS. While, Detroit was not selected as one of the original DPM demonstration cities, UMTA officials promised Detroit city officials that its proposed DPM project would receive sympathetic consideration for funding under UMTA's $1.2 billion (1989 dollars) commitment for transit projects in the Detroit metropolitan area.

While the public debate focused on disagreements about the regional transit system, i.e. whether to build a heavy rail system and subway or a light rail regional transit system with expanded bus service, SEMTA proceeded with planning for the DPM. Since the project was viewed as being free, there was little opposition. Planners and policy makers anticipated that the project's capital costs would be paid by UMTA and the State of Michigan, and project planners claimed fares would more than cover operating costs.

In October, 1979, SEMTA completed a draft EIS for the DPM and scheduled public hearings. While there were detailed discussions of alignment and station location issues, there were no serious questions raised about the overall merit of the DPM concept, or the project's cost and ridership projections. In May, 1980, the SEMTA board approved the DPM project and submitted a final EIS to UMTA. The 2.9 mile single-loop system was to cost $167.8 million (1989 dollars).* In November, 1980, SEMTA received proposals from two vendors Matra/Otis and Urban Transportation Development Corporation, Ltd. (UTDC) (Cambridge Systematics, 1988, pp 3-25).

In January, 1981, just after SEMTA selected UTDC as the system supplier, UMTA announced the cancellation of the Downtown People Mover Demonstration Program. Detroit remained committed to the scheme, however, and in spite of the Administration's efforts to discontinue the program, successful lobbying efforts led by Congressman Carl Pursell resulted in an appropriation for the system. Construction of the Detroit DPM began in November 1983 and took approximately four years: service began in August, 1987, one year behind schedule. Much of the delay was attributed to the fact that neither SEMTA nor UTDC, the system contractor, had ever undertaken a project of this magnitude.

Public support for the DPM began to weaken when the start of construction was closely followed by a series of cost increases and project delays. At that time, public attention shifted from the debate over the nature of the larger regional system to the DPM project, and, as the projected capital cost of the system increased by 56 percent during the first 18 months of construction, SEMTA's credibility slowly eroded. Controversy about the project intensified when it

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* Pickrell (1989, p. 33) presents a 1980 nominal dollar estimate of $109 million for circa 1991-93 and $144 million in 1988 dollars (converted to $147 million in 1989 dollars here).

became clear that local contributions to capital costs would be required, and that federal grants for the DPM would displace federal contributions to other regional transit projects.*

In August 1985, SEMTA offered to turn the DPM project over to the city. Soon thereafter, in October 1985, the Governor of Michigan and Detroit's Mayor, Coleman Young, agreed to assume responsibility for all DPM costs in excess of $274 million (1989 dollars) and created a non-profit corporation, the Detroit Transportation Corporation, to manage the DPM project.

The Miami Metromover

The Miami Metromover system, like the Detroit DPM, is an elevated automated transit system that operates in a loop connecting the major downtown activity centers.** In contrast to the Detroit DPM, however, which operates in only one direction, the Miami Metromover is double tracked and two directional. More importantly, Miami's metromover was implemented to serve as a downtown distributor for Miami's disappointing Metrorail system.*** A large part of the discrepancy between projected and actual ridership for the Miami DPM (recall actual ridership is only 26 percent as large as forecast ridership) is due to the fact that Metrorail ridership in 1988 at 35,400 boardings per day was only 15 percent as large as the 239,900 daily trips projected by system planners (Pickrell, 1989, p. 15).

The Metrorail alignment does not serve the CBD directly, it runs north-to-south on the western edge of the Miami CBD (see Figure 13-4). The Metrorail alignment along the western fringe of the CBD meant that downtown distribution/circulation would be a problem. The Metromover was meant to supplement the Metrorail by providing a moderate cost and less intrusive elevated guideway that would provide downtown distribution for the regional system. Metrorail alignments which would have directly served the CBD were rejected due to high land acquisition and tunneling costs, inadequate right-of-way, and environmental considerations.

The Metromover's nine stations serve an area with an estimated 50,200 jobs and 3,200 residents in 1987 (Pickrell, 1989). As Figure 13-4 indicates, Miami's DPM runs from the Government Center, where it shares a station with Metrorail, south and east to the CBD's shopping district and office corridor, north to the downtown campus of Miami-Dade Community College, and west past the Courthouse complex back to Government Center. Planned extensions would add two legs to the Metromover for a total system length of 3.9 miles. These extensions would serve the Omni area, located north of the CBD, and the Brickell office corridor, located south of the CBD.

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* Pickrell (1989, p. 91) estimates that the city of Detroit paid $2 million of the estimated $156 million (nominal dollars) of the DPM project and the State of Michigan paid $39 million. The forecast amounts were zero local dollars and a $24 million State contribution (again i nominal dollars).

** This section also draws extensively on Cambridge Systematics Inc. (1988).

*** Metrorail, Miami's heavy rail transit system, is 21.5 miles long and runs from Hialeah in the northwest to Dadeland in the south on an elevated guideway. It has 20 stations and began service in 1984 (the full 21.5 mile system went into operation in May, 1985).

Round trip time on each loop is approximately 10 minutes, with an average vehicle speed of approximately 10 mph. The Metromover system uses 12 automated, rubber-tired, single car vehicles supplied by Westinghouse. Each car has a maximum capacity of 155 passengers. The system is designed to have seven cars operating in the peak direction loop during peak periods, with a capacity of 6,500 trips per hour. During off peak periods, the operating plan called for five vehicles operating on each guideway at two-minute headways. Except in the system's southeast quadrant, where it was decided to split the alignment to reduce the system's visual impact on narrow streets, the two tracks are combined in a single structure. Maintenance and storage facilities are located between the guideways, thereby allowing access from each track.

The Miami Metromover was planned and implemented, and, is being operated by, the Metro-Dade Transportation Administration (MDTA) which also operates, in separate divisions, Metrorail and Metrobus (the regional bus system). Westinghouse constructed the Metromover, underbidding UTDC and Matra/Otis as system supplier for the turnkey system in 1981.

As with the Detroit DPM, only a small fraction of the trips on Miami's Metromover are worktrips. Most are off-peak social-recreation trips, including midday intra-CBD trips from work to shopping and restaurants.

MDTA contends the larger part of the project cost overruns are attributable to underestimates of right-of-way acquisition costs, design changes to facilitate transfers between Metromover and Metrorail at Government Center, under-budgeted guideway costs, and the coordination of the guideway with other downtown road improvement projects (Cambridge Systematics, 1988, p. 3-41).

Planning of the Miami Metromover

In the late 1960s, in response to widespread public opposition to proposed highway and expressway improvements, Dade County officials developed a "balanced" transportation plan which included bus system improvements and a regional rail rapid transit system.* Dade County voters "accepted" the County's transportation plan in 1972 and approved a $1.4 billion "Decade of Progress" bond issue, $348 million of which was earmarked for the local share of transit improvements (all figures are in 1989 dollars). The proposed transit improvement program included a rail rapid transit system, Metrorail, expansion of the bus system from 550 to 920 buses, and a downtown distribution system to link major activity centers with other transit facilities.

The Miami Urban Area Transportation Study, completed in 1972, first proposed a downtown people mover for Miami as a link between the downtown and a proposed rapid transit system. When UMTA announced its DPM competition, the City of Miami and Metro Dade County

* Dade County is made up of 27 municipalities, including the City of Miami, the county's largest municipality. In 1957, under Florida's Home Rule Amendment, voters in Dade County established a regional government with broad powers including exclusive responsibility for all transportation functions within the urbanized area. The Metropolitan Transportation Administration (MTA) was organized in 1961 to unify the region's private operators into a single public transportation system. In 1974, MTA became an agency of metro government under direct control of the county manager. MTA became the MDTA in 1981, when MTA bus operations were merged with the Office of Transportation Administration which had responsibility for development of the rail system.

immediately established a DPM policy committee to develop a DPM proposal for submission to UMTA. The Policy Committee recommended building a DPM in two phases, with a 1.9 mile CBD loop to be built with funds secured through the original proposal to UMTA and the two legs to be constructed at a later date. The capital funding plan included an 80 percent UMTA contribution, 10 percent from the Florida Department of Transportation, five percent from Dade County, three percent from the City of Miami, and two percent from the private sector (through the establishment of a special taxing district). In June 1976, the city and county adopted the DPM proposal and submitted it to UMTA. Miami was chosen as one of the finalists and was given provisional approval. In December 1977, UMTA reconfirmed its commitment to cover 80 percent of the capital costs for Miami's proposed DPM.

In November 1980, UMTA accepted the Final EIS and Miami put the system supplier contract out to bid. Westinghouse, UTDC, and Matra/Otis submitted "acceptable proposals" and MDTA signed a $99.3 million contract with Westinghouse (1989 dollars). The EIS considered an expanded bus system alternative for downtown circulation, but the Committee determined it would be less effective at meeting local objectives than the DPM. In particular, the study found that the all bus alternative would have higher operating costs, consume more energy, increase street congestion, and produce more emissions than the recommended people mover system. Overall the committee concluded, the DPM would provide a higher quality of service, greatly enhance use of the Metrorail system, and be more effective at stimulating development and revitalization in downtown Miami (Cambridge Systematics, 1988, p. 3-38). On June 15, 1979, the county and the city accepted the committee's recommendation to construct Stage 1 of the downtown people mover system.

The DPM project engendered surprisingly little controversy in either Miami or Dade County. As in Detroit, the downtown business community strongly supported the project; Miami's media, policy makers, and the public were more concerned with the far larger Metrorail project; and most of the funds for construction of the project were to come from the federal government.

As MDTA was gearing up to start Metromover system construction, the Reagan Administration announced the cancellation of the DPM program. Congressman Lehman of Miami, Chairman of the Transportation Subcommittee of the U.S. House Appropriations Committee, used his position to gain UMTA's commitment to continued funding, although at reduced levels, for Metromover and thereby guarantee the future of Miami's DPM.

Groundbreaking for the Metromover was held on August 31, 1982. Project delays were caused by slower than expected right-of-way acquisition, problems with determining the location of utility lines, and the inability of some subcontractors to meet schedules. In contrast to the Detroit DPM, no major technical problems were encountered in completing the Miami DPM. Construction of the Metromover by the Westinghouse Corporation was completed in 1986 two years behind schedule.

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Chapter 14. Cost-Effectiveness of Exclusive Busways vs. Rail

Introduction

The principal attraction of exclusive and shared busways, relative to light and heavy rail systems, is their generally lower capital cost per rider, their greater flexibility, and the fact that in many circumstances they provide lower door-to-door travel times than even high performance, grade separated rail systems. This chapter compares the cost-effectiveness of exclusive busways to light and heavy rail transit. The final section considers guided bus systems, a hybrid technology that according to its advocates provides all of the advantages of either exclusive busways or LRT and has none of their disadvantages. The next chapter extends the discussion to an examination of the design and cost-effectiveness of shared busways and other bus-HOV facilities.

The extent of busway capital cost savings, relative to rail systems serving the same corridors, depends on many factors including system length, expected ridership levels, whether service is provided in both directions or only one, design standards, and service characteristics. Bus rapid transit systems typically have lower capital costs than rail transit because bus systems: (a) do not require the expensive electrical systems used in rail rapid transit systems, and (b) are generally shorter.

Somewhat surprisingly, given the clear-cut cost advantages of bus rapid transit in most situations, and the extensive scholarly literature documenting these advantages, alternatives analyses comparing exclusive busways and rail rapid transit for particular metropolitan areas typically find that total system costs, and, in some instances, even the capital costs, of light and heavy rail systems, are less than those of comparable exclusive busway systems. This outcome, which has become more difficult to achieve with increasing federal oversight of the "Alternatives Analysis" process, can usually be explained by a prior commitment to rail and a willingness to "cook the numbers" until they yield the desired result. Before we examine this phenomenon, however, we first briefly summarize the findings of the scholarly literature on the comparative costs and performance of rail and bus systems.

The Era of the Streetcar Railway

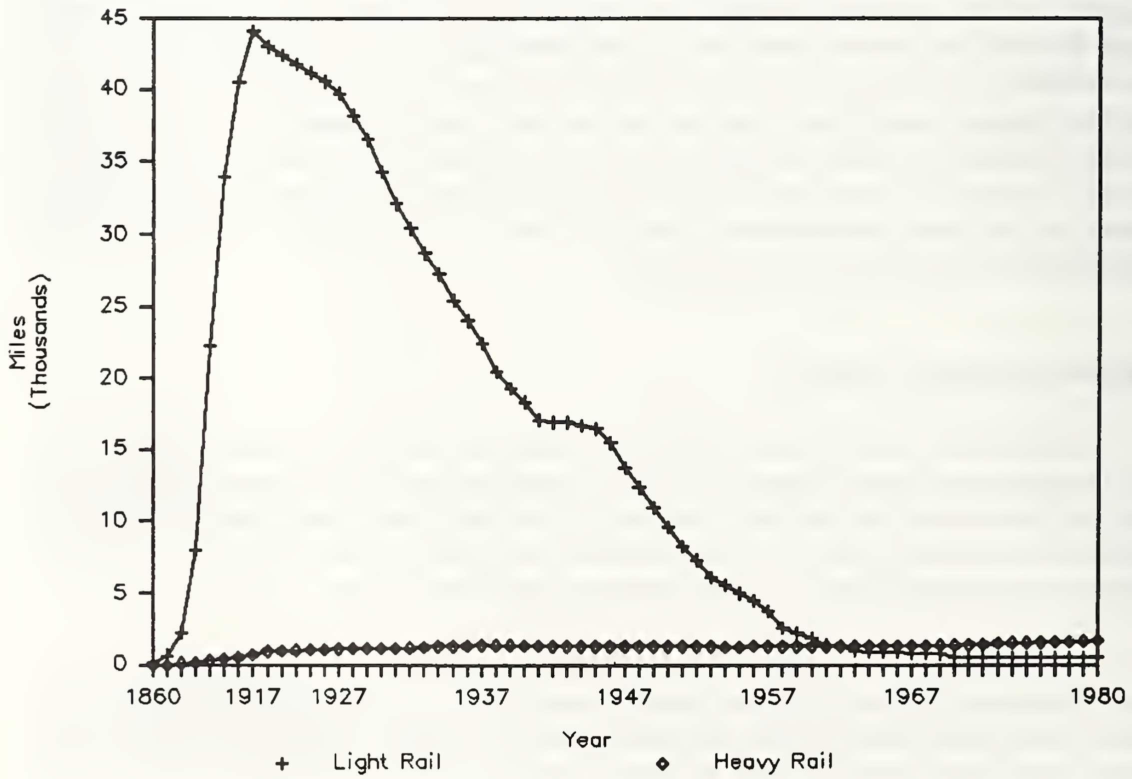
What has come to be known as light rail or Light Rail Transit (LRT) bears a close resemblance to the electric street railways that briefly dominated the nation's urban transportation scene after their invention at the turn of the century. The emergence, rapid growth, and decline of electric street railways, popularly known as streetcars, trams, or trolleys, is thus a useful starting point for a discussion of the cost-effectiveness of urban rail systems.

As Figure 14-1 shows, the first street railways, i.e. streetcars, were introduced in the United States during the late 1890's as replacements for slower and more expensive horse cars, which by 1890 were providing 5,662 single track miles of service. The lower cost and higher performance electric railways quickly displaced horse and mule cars, and by 1902 only 259

miles of horse car operations remained in service, as compared to 22,000 miles of electric street railway operations. Electric street railways continued their rapid expansion until 1917, when they reached a peak penetration of 44,119 miles. Thereafter, surface rail mileage in American cities fell rapidly as increasing numbers of private transit operators replaced costly, low volume, street railway services with less costly bus services. World War II provided a temporary respite, but following V-J day, private bus operators once again began replacing their remaining street railway systems. Street railway operations reached a low of 484 miles in 1974, before slowly increasing to 495 miles in 1980.

As Figure 14-1 indicates, the more costly and less numerous heavy rail systems have led a less volatile history. The first five miles of grade separated heavy rail rapid transit began operations between 1860 and 1870, and by 1902, 313 single track miles were in place. Rail rapid transit mileage thereafter increased to 530 miles by 1912, and nearly doubled during the next 12 years, reaching 1,007 miles in 1924. Mileage then grew slowly until 1937, when it reached a pre-World War peak of 1,379 miles. Thereafter, rail rapid transit mileage started to slowly decline until it reached a low point in 1954, when 1,272 miles were in service. From that point, the completion of new starts and extensions to existing systems slowly increased rail rapid transit mileage. In 1986, there were 1,312 directional route miles and 1,695 miles of track nationally (Chapter 2, Table 2-1).

Figure 14-1. Miles of Light (Surface) and Heavy Rail Transit by Year, 1860-1980



The Light Rail Revival

In spite of widespread abandonments between 1920 and 1939, there were nonetheless 16,480 miles of surface rail, i.e. streetcar/LRT, services operating in United States cities at the end of World War II. By 1980, this number had declined to a mere 495 miles as both private and public operators replaced the costly to maintain and operate street railway systems with diesel and electric buses. While most of the services abandoned after World War II were streetcars operating in street right-of-ways, many of these services also operated in exclusive or near exclusive right-of-ways. Proponents of urban rail systems during most of the post World War II period emphasized the need for costly, high performance, heavy rail systems to "compete with the private auto" and exhibited little interest in light rail. Rail enthusiasts became interested in light rail only after a number of newly constructed heavy rail systems turned out to be far more costly and less effective than their proponents had hoped.

In 1981, San Diego opened the first entirely new LRT system planned and built since before World War II.* Since then seven U.S cities have added nearly 83 miles of new LRT services, and Pittsburgh replaced part of its old and decrepit streetcar system with a modern LRT system. Cities and transit authorities became seriously interested in LRT when it became apparent that fully grade separated heavy rail was simply too expensive for low and medium density operations in most American cities, and perhaps more importantly, when the Reagan administration sharply reduced funding and imposed tougher criteria for new rail starts.

Comparative Costs of High Performance Bus and Rail Systems

More than twenty-five years ago Meyer, Kain, and Wohl (1962) published the first "objective" comparative cost estimates of alternative urban transportation technologies in a study completed for the White House Commission on Civilian Technology. Both this study and more extensive analyses published three years later by Harvard University Press demonstrated that heavy rail transit had substantially higher costs per passenger trip than bus rapid transit in all but a few situations. The Meyer, Kain, and Wohl (1965) analyses added that continued increases in per capita incomes and trends in urban development would further narrow the circumstances where rail transit would be a cost-effective alternative to some form of bus system.

The Meyer, Kain, and Wohl cost analyses, which considered both operating and capital costs and allocated all capital costs to peak hour users, provided estimates of one-way passenger costs for peak hour corridor volumes ranging between 5,000 and 50,000 passengers and for systems built in high and medium density metropolitan areas. In contrast to previous studies, which generally considered only the line-haul portion of the typical commuter trip, Meyer, Kain, and Wohl also analyzed residential collection and downtown distribution costs.

The cost curves shown in Figure 14-2 for the line-haul portion of a typical commuter trip illustrate how the one-way passenger trip costs of each mode vary as corridor volumes increase

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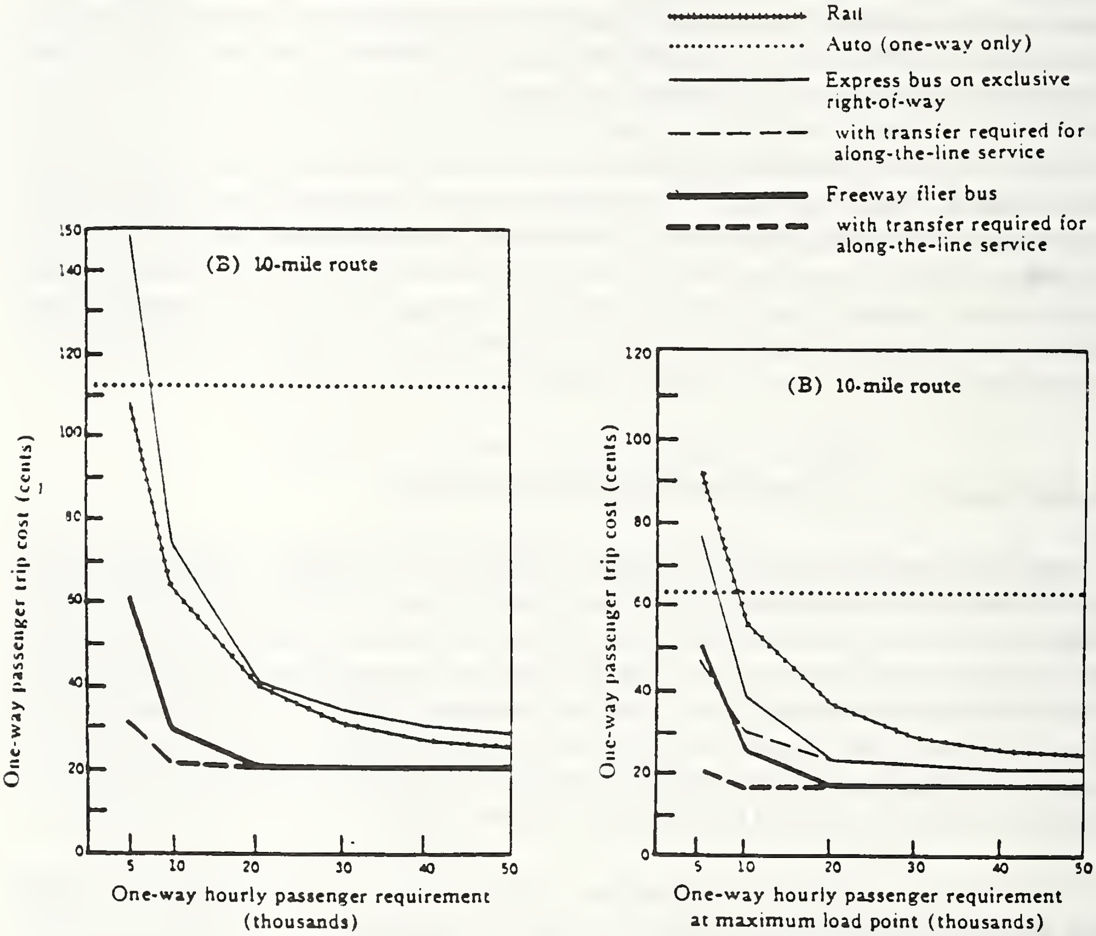
* Schumann (1988) reports that "only three significant trolley projects were undertaken from the end of World War II through the late 1960's. He identifies these as: 1) extension of Philadelphia's surface car subway from 23rd to Market Streets and to the University of Pennsylvania in 1955; 2) Conversion of Boston's Riverside Line from diesel-powered commuter rail to light rail in 1959; and 3) Opening of Leonard's M&O (now Tandy) subway in Fort Worth.

Figure 14-2.

Line-Haul, One-Way Passenger Trip Costs for High (Chicago) and Medium (Pittsburgh) Density Metropolitan Areas with Complete Two-Way Service



High Density

Medium Density

Source: Meyer, Kain, and Wohl (1965, pp. 236-7).

for a 10 mile line built in a high, i.e. Chicago, or medium, i.e. Pittsburgh, density metropolitan area. Most metropolitan areas in the United States that are currently building or planning rail systems have significantly lower densities than were assumed for the Meyer, Kain, and Wohl medium density case, and thus the argument for heavy rail transit in these cities is even less favorable than is suggested by these curves.

The Meyer, Kain, and Wohl analyses yielded the following broad generalizations about the costs and performance of alternative high-performance systems:

- Private autos with 1.6 persons per car had the lowest cost per passenger trip of any of the "high-performance" modes considered at surprisingly high volume levels (up to 5,000 persons per hour).

- Door-to-door travel times and other performance characteristics for the auto mode were substantially better than those of any of the other modes considered.

- As auto occupancy increased, through carpooling or other means, the costs per passenger trip of the auto mode decreased sharply, although door-to-door travel times deteriorated.

- Express buses operating on exclusive busways had significantly lower costs per passenger trip than heavy rail systems in all but a few situations.

- Heavy rail had lower per trip costs than express bus on exclusive rights-of-way only when routes were very short, peak-hour volumes were very high, and net residential densities were very high.

- "Freeway Fliers," i.e. express buses operating on uncongested, but shared, express highways, had substantially lower costs than heavy rail, bus on exclusive right-of-way, or private autos at all peak hour volumes and in every situation considered.

While the Meyer, Kain, and Wohl comparative cost results were bitterly attacked by rail transit advocates, their general outlines have been confirmed by all but one of the small number of "objective" comparative cost analyses that have been completed (Hamer, 1976). Studies for the Institute of Defense Analysis (IDA) (Boyd, Asher, and Watzler, 1973) and by Keeler, Small, and Associates (1975) as part of the BART impact study, for example, used procedures that were similar to those developed by Meyer, Kain, and Wohl and reached similar conclusions.

The methodologies used by the authors of the IDA and BART Impact Studies differ from that used by Meyer, Kain, and Wohl (1965) principally in terms of including the value of travel time incurred in the cost of alternative modes.* Since private cars and some express bus sys-

* Hamer (1976, pp. 43-49) presents both a cogent and critical summary of the IDA report and a discussion of the criticisms of this report by rail enthusiasts. He adds further that "this report, while drawing heavily on the study by Meyer, Kain, and Wohl, is in fact considerably narrower in focus. Mode evaluation is made for CBD traffic with no peak period along-the-line or reverse flow patronage considered in designing and costing out operational strategies. The report has thus attracted severe criticism for being myopic, a criticism which has been extended unfairly to the Meyer, Kain, and Wohl book by those who noted the intellectual debt involved, but failed to read The Urban Transportation Problem."

tems have lower door-to-door travel times than even high-performance, heavy rail systems, inclusion of travel time strengthens Meyer, Kain, and Wohl's conclusions about the relative costs of heavy rail and express bus systems.

Meyer, Kain, and Wohl made a conscious decision not to include trip time as a cost in assessing the relative costs and cost-effectiveness of various modes. Instead, they sought, to the extent possible, to represent these aspects of service quality as "minimum service levels," and confined per trip costs to the capital and operating costs of each system. The relative travel times of the several modes, however, affect ridership and thus the applicable volume levels or thresholds in Figure 14-2. The disadvantage of the approach used by Meyer, Kain, and Wohl is that trip time is in fact a cost and failure to include it tends to bias the analysis toward high capacity rail and exclusive busway modes. The advantage is the maintenance of a clear distinction between cost and supply considerations and system benefits and the determinants of demand.

It is perhaps worth noting that none of these studies, perhaps because they were excessively influenced by the experience summarized in Figure 14-2, paid much attention to LRT or commuter rail in their formal cost analyses. The reason was that "informal" analyses quickly persuaded the authors of all three studies that the decisions of private and public transit operators to replace streetcars, trolleys, trams and other forms of low performance rail transit with electric and diesel buses were correct, and that new light rail transit systems were completely dominated by heavy rail, bus rapid transit, or local bus.* Higher performance, i.e grade-separated LRT systems, moreover, generally have lower capacities than heavy rail and, at the same time, retain all of heavy rail's disadvantages (costly, exclusive right-of-ways and structures, fixed route structures, and an inability to pass or to operate off the rail right of way).** At lower peak hour volumes, moreover, it was clear that LRT and commuter rail are strongly dominated by local buses or by bus rapid transit operating on either exclusive right-of-ways or on an appropriate mix of exclusive, shared express, and shared local streets and roads.

While the distinctions between heavy rail, LRT, and commuter rail systems are somewhat arbitrary, the key differences are the source of locomotive power and the extent of grade separation. All heavy rail systems obtain their power from a third rail, while LRT and commuter rail systems usually obtain theirs from an overhead wire, or in the case of some commuter rail systems, from diesel locomotives. For reasons of safety, the right-of-ways of heavy rail systems must be protected from pedestrians and riders and be completely grade separated; in contrast, LRT and commuter rail systems, their power sources located out of reach of both people and vehicles, may operate partially or entirely at grade.

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* Decisions to abandon these light rail systems, many of which had extensive "exclusive" ROW, were taken at a time congestion on urban streets and roads was quite low. As car ownership and congestion levels rose, degrading bus speeds and performance, some of the operators of these light rail systems may have wished they could reconsider their decision.

** Hamer (1976, p. 36) offers the following pessimistic assessment of the value of the then emerging light rail technology. "In the final analysis 'light rail' systems are as inflexible in their configuration as conventional rail systems. They also lack the ability of express bus networks to act as their own feeder. The sudden popularity of 'light rail' thus appears to be without much merit unless placed in a special context. A low-volume transit corridor in an area with extraordinary topography or very inadequate arterials <u>might</u> justify a low-capacity subway line joined to a minimally grade-separated surface system. The number of instances where such requirements are absolutely unavoidable are too few to make 'light rail' a subject for serious consideration as a regional transit system."

Because heavy rail systems are completely grade separated, they typically are able to achieve much higher speeds and better reliability than LRT systems with less grade separation or buses operating on congested roads. At the same time, heavy rail systems pay a steep price for their higher speeds and greater reliability, as the costs of complete grade separation are very high. The extent of grade separation, and thus the speed and reliability of light rail systems, vary widely. LRT's principal attraction, relative to heavy rail, is much lower capital costs - at least where extensive grade separation is not provided.

LRT capital costs and line haul trip speeds both increase as the fraction of right-of-way that is grade separated increases; a completely grade separated light rail system should be able to achieve line-haul speeds that are very close to those of high-performance, heavy rail systems. Unfortunately, the capital and operating costs of such high-performance LRT systems will also be very close to those of high-performance, heavy rail systems. LRT feasibility studies all too often claim the capital costs savings obtainable from limited grade separation and at the same time assume the speed and reliability that can only be achieved in a rail system with complete grade separation.

We continue to be puzzled by the persistent popularity of Light Rail Transit. LRT seems to us to be nothing more than a slow and expensive bus that cannot pass and is unable to operate on the city streets. Because of LRT's inability to operate off of its guideway, virtually all LRT users must transfer from feeder buses or private automobiles, with predictably adverse effects on ridership.

Suburban/Commuter Rail

Extensive commuter rail systems carried large numbers of suburban commuters in a number of United States cities until the end of World War II, and smaller systems, carrying far fewer commuters, still exist in New York City, Chicago, Philadelphia, Boston, and a number of other U.S. cities. After World War II, rapid increases in per capita incomes, extensive highway improvements, and rising levels of car ownership caused steady declines in the ridership of these commuter railroads, in spite of huge increases in suburban populations. Even so, as the data presented in Chapter 2 (Table 2-1) indicate, there were still 3,183 directional route miles of commuter rail serving United States cities in 1986, a figure that is 85 percent larger than the combined directional route miles of heavy and light rail/streetcar systems in the same year.

The characteristics of suburban commuter rail systems vary widely. In most instances they share tracks with inter-city passenger and freight trains. Much of the appeal of commuter rail arises from the fact that these services can often be implemented relatively quickly at a capital cost that is often substantially less than the cost of a new rail rapid transit system. The right-of-way, often with extensive grade-separation, and, in many cases the tracks, already exist, and modest commuter operations can be introduced at the cost of acquiring suitable rolling stock. In many instances suburban rail systems use cars and locomotives similar to those used for inter-city services. In other cases they use self-propelled diesel or electric cars or self-propelled vehicles, similar to those used in heavy rail transit or LRT systems.

In spite of the widespread tendency to think of commuter rail as cheap rail transit, experience throughout the world demonstrates that the notion that commuter rail services can pro-

vide low-cost commuter transportation is largely illusory. Few, if any, examples of unsubsidized commuter rail operations exist, and in most instances the subsidies for commuter rail operations per passenger carried are enormous, typically exceeding those required for even light and heavy rail transit. System costs, moreover, rise dramatically as available excess capacity is used up and new capital outlays are undertaken to increase system capacity or improve performance.

When a suburban railway is part of a multipurpose rail system, its capacity and performance depends on the amount and type of track sharing. It is unusual to find suburban rail lines capable of carrying more than 10,000 to 20,000 passengers in the peak hour at the maximum load point, and the actual patronage of most lines is much less. Where sufficient track priority or exclusive use is given to suburban rail systems, however, their capacity and performance may approach those of modern heavy rail transit systems. The recently upgraded suburban railway in Porto Alegre, for example, has an estimated capacity of 48,000 per hour in one direction (Armstrong-Wright, 1986, p. 22). Stations are about 1.2 miles apart, however, and the Porto Alegre line currently carries only about 10,000 passengers in the peak hour.

Urban Rail in America

Urban Rail in America is the only significant scholarly study of rail and bus transit to conclude that new rail transit systems would have lower costs than bus transit in a wide range of circumstances in United States urban areas (Pushkarev and Zupan, 1980). Differences in the terminology and approach used by Pushkarev and Zupan and earlier comparative cost studies make it difficult to determine why Pushkarev and Zupan results differ so dramatically from those obtained in earlier scholarly studies. Fortunately, Don Pickrell (1984) has completed a painstaking reanalysis of the Pushkarev-Zupan study which clarifies these issues. Pickrell identifies two major sources of error in the Pushkarev-Zupan cost analyses; he finds that Pushkarev and Zupan, (a) understate both the capital and operating costs of new rail systems relative to bus systems, and (b) use somewhat optimistic ridership projections when they apply their cost estimates to particular metropolitan areas.

Pickrell shows that Pushkarev and Zupan overstate the operating cost savings of light and heavy rail systems because they compare "actual" bus system costs with "idealized" rail system costs. When Pickrell replaces Pushkarev and Zupan's "idealized" rail costs with more realistic "best practice" costs for new rail systems much, if not all, of the alleged operating cost advantages of rail systems disappear. Similarly, using more extensive and detailed capital cost data for new rail systems, Pickrell determines that Pushkarev and Zupan significantly underestimated rail system capital costs.

As the figures in Table 14-1 reveal, Pickrell's "corrections" have a dramatic impact on the Pushkarev-Zupan findings. The first column expresses bus/rail thresholds in terms of passenger miles per lane mile, the convention used by Pushkarev and Zupan, while the last two columns define them in terms of peak hour volumes in the peak direction at the maximum load point, the convention used by Meyer, Kain, and Wohl and most other comparative cost studies. The bus/rail break even point for an at-grade or elevated 10 mile, heavy rail line with none of its mileage in tunnel increases from 30,000 to nearly 200,000 peak hour passengers. Similarly, applying Pickrell's corrections increases the break even point for a light rail system with little or no grade-separation from 8,000 to more than 21,000 per peak hour.

Table 14-1. Rail/Bus Thresholds for 10 Mile Line-Haul System *

Type of Facility	Pushkarev-Zupan PM/LM	Pushkarev-Zupan MP/PH	Pickrell MP/PH
Heavy Rail Transit			
Above Ground	15,000	30,000	199,473
One-Third Tunnel	24,000	48,000	245,958
All Tunnel	29,000	58,000	340,336
Light Rail Transit:			
(Grade Separation)			
Little or None	4,000	8,000	21,297
Considerable	7,000	14,000	37,270
One-Fifth Tunnel	13,500	27,000	61,000

* Thresholds are defined in terms of PM/LM (passenger miles per line mile) and MP/PH (peak hour passengers in the peak direction assuming an average trip length of five miles, i.e. equally distributed boardings); they reflect the ridership level at which rail transit has a total cost advantage over bus transit.

Source: Pushkarev and Zupan (1980, pp.xviii and xix), and Pickrell (1984).

The Pushkarev-Zupan rail/bus thresholds shown in columns one and two of Table 14-1 are based on comparisons of rail transit to local buses operating on congested streets and roads. The bus cost models used by Pushkarev and Zupan (1980, pp. xiii, 114-8) in obtaining these threshold figures, for example, assume bus operating speeds of only 12 mph. In contrast, Meyer, Kain, and Wohl and subsequent comparative costs studies assumed buses would operate on exclusive or congestion controlled right-of-ways and would thus be able to attain speeds equal to or better than heavy rail.

The Meyer, Kain, and Wohl analyses, for example, require all of the high performance systems considered to maintain an average line haul-speed of at least 35 mph, except in the case of very short trips where the 35 mph constraint is replaced by a requirement that line-haul round trip travel time must be less than 10 minutes. A careful reading of Urban Rail in America reveals that the use of local buses operating on congested roads as the base case is critical, the comparisons are much less favorable to rail transit when express buses are used for the comparisons:

> To attain lower labor cost than express buses operating at a speed equal to rapid transit or light rail (20-25 mph or 32-40), volumes on rapid transit must be one-and-one third to twice as high as the threshold of existing service, depending on service frequency, and those on light rail, twice as high even with low service frequency; fully attended stations can be provided at about three times the threshold of existing service (Pushkarev and Zupan, 1980, p. xiii).

Bus rapid transit has several inherent technological advantages over heavy rail transit, LRT, and suburban rail systems that should enable it to perform better than these modes in most situations, and particularly where origins and destinations are widely dispersed as in Los Angeles, Dallas, Houston, Seattle, Phoenix and other 20th Century cities. The small unit size of buses, frequently cited as a disadvantage by advocates of rail transit, is actually an advantage in many situations, since it permits more frequent and/or more direct service and lower trip times.

When bus transit is provided with an exclusive or uncongested, grade-separated right-of-way, it can achieve higher line-haul speeds than light or heavy rail transit, and its dominance becomes even greater when door-to-door travel times are considered. In developed countries, the emphasis has been on developing exclusive busways and freeway based, express bus systems that can achieve line haul speeds of 50-60 mph. Light and heavy rail systems have lower line haul speeds than high-performance, bus rapid transit in most situations because trains cannot pass one another, even where patterns of demand and trip volumes would permit. As peak hour volumes decline and routes become longer, the performance advantages of bus rapid transit operations increase.

As we discussed in Chapter 12, planners in developing countries have increasingly turned to bus-lanes and low-cost, at-grade, segregated busways capable of handling large volumes of trips at somewhat lower line haul speeds to accommodate the rapid growth in travel (Kain, 1988b). Advocates of segregated busways in developing countries contend that while at-grade, segregated busways generally have lower line-haul speeds than modern metros or largely grade-separated LRT systems, door to door travel times are often very similar (Kain, 1988b). Stops on segregated busways are twice as frequent as on the typical metro or LRT, and in many situations the same bus acts as the residential collector, i.e. feeder, and as the line haul vehicle, saving travelers the inconvenience and increased travel time associated with transfers.

A recent World Bank study presents estimates of total system costs (including operating costs, depreciation, and interest charges) using unit costs that are generally applicable to cities in developing countries (Armstrong-Wright, 1986). As Table 14-2 indicates, rail system costs are three to five times as high as bus system costs; the "bus in expressway" system is apparently a segregated busway with extensive grade-separation.

Since rail costs per passenger trip in developed countries are substantially higher than bus costs, advocates of rail transit generally resort to other arguments to justify investments in rail transit. The most common claim is that the capacity of the streets or of bus transit is insufficient to accommodate future travel. As we discussed in Chapter 11, the CBD street capacity argument is widely used in the United States as well. In some instances the capacity argument focuses on corridor demands and capacity, while in others it emphasizes the demand for and capacity of central area street systems. In making these arguments, the proponents of rail

Table 14–2. Total System Costs (in 1989 U.S. Dollars) for Various Modes *

System	Cost per Passenger Mile
Bus in Mixed Traffic	0.02 – 0.05
Bus in Reserved Land	0.02 – 0.05
Bus in Expressway	0.05 – 0.09
Tramway	0.03 – 0.11
LRT (Surface)	0.11 – 0.16
Rapid Rail (surface)	0.11 – 0.16
Rapid Rail (Elevated)	0.13 – 0.21
Rapid Rail (Underground)	0.16 – 0.27

* Total system costs include operating costs, depreciation, and interest charges.
Source: Armstrong–Wright (1986).

transit systems ignore or are ignorant of the large passenger volumes currently being carried by bus systems in a number of cities throughout the world; the experience of bus systems in several developing countries, discussed in Kain (1988b), is thus highly relevant. A sampling of these data is provided in Chapter 11 (Table 11-4).

The comparative cost analyses and claims about the cost effectiveness and operational feasibility of high-performance and high-capacity of bus rapid transit systems made by Meyer, Kain, and Wohl a quarter of a century ago have stood the test of time. Subsequent studies for North America suggest their findings about the superiority of bus rapid transit in medium and low density cities were valid and, if anything, conservative. Yet as we discuss below, alternatives analyses for particular urban areas often find light and heavy rail would have lower costs than exclusive busways.

The Use of Strawmen

The most common way of obtaining the result that a light or heavy rail system would be cheaper to build than an exclusive busway is to assume the busway will operate in exactly the same manner as the preferred rail alternative (thereby sacrificing many of the advantages of the bus rapid transit technology), and to "overdesign" the busway alternative.

Kain (1992) discusses of the use of "strawmen" by Houston's transit authority (METRO) in 1987 and 1991 alternatives analyses of proposed rail systems. Michael Berryhill and David Butler, moreover, describe METRO's use of strawmen in earlier assessments of proposed rail schemes. They made the following observations in an April 1983 article published in Houston City Magazine.

> METRO studied busways ... and found them slightly cheaper to construct than rail, but more expensive to operate. METRO's busway estimates ... were so high ... because they were overdesigned. The busway designs in that analysis called for purchasing new rights-of-way and building busways six lanes wide, with two lanes and a breakdown lane running in each direction. METRO also theorized that people should take a bus to the busway, adding expensive stations and unnecessary transfer and waiting time.
>
> Such busways are excessive. A three-lane, elevated busway built over the existing right-of-way of the Southwest Freeway is capable of carrying the passenger demand. Because traffic is congested in both directions during rush hour, the Southwest Freeway would require one lane of busway in each direction with a breakdown lane in the middle. The extra lane permits the bus to turn around and rapidly return to make another trip. Busways in other corridors don't require the extra lane because buses can make the return trip with auto traffic.
>
> ... Busways failed in METRO's alternatives analysis because they were designed to fail (Berryhill, 1983 p. 7).

Berryhill subsequently elaborated these arguments in a 1984 article published in The Houston Post:

> Busways have one serious problem in the eyes of many transit planners, however. They make trains look expensive. They make trains look so expensive, in fact, that Houston's transit planners had to distort the costs of busways in order to make heavy rail look economically feasible. Now that heavy rail seems to be categorically ruled out as too expensive, METRO planners are going to have to admit they were wrong when they reported that both light rail and busways were inferior to heavy rail.
>
> METRO wanted the costs of busways to be high, I think, in order to give light rail a chance. Every dollar of reduction in the cost of busways makes rail, even the least expensive forms of light rail that have to mingle with traffic, that much more out of reach (Berryhill, 1984)).

Houston's experience is by no means unique. As Hamer (1976) and Kain (1990) point out, the use of strawmen, the imposition of constraints, and the preparation of inflated land use (particularly CBD employment) and ridership forecasts are all too commonplace. We now consider these issues in the context of Atlanta's decision to build rail.

Rail Planning In Atlanta

Atlanta's first post World War II rail rapid transit proposal was advanced by the Atlanta Region Metropolitan Planning Commission (ARMPC).* The ARMPC proposal, completed in 1961, envisioned a five-county, 60 mile heavy rail system, built largely along existing railroad rights-of-way, with 32 stations.

A refined version of the ARMPC heavy rail system, developed by the engineering firm of Parsons, Brinkerhoff, Quade, and Douglas,(PBQ&D) was published in December 1962 and was endorsed soon thereafter by a special state legislative commission created to review metropolitan Atlanta's transportation problems. The principal difference between the PBQ&D plan and the earlier ARMPC proposal was that the PBQ&D plan added a subway down the Peachtree Street "spine," in place of an alignment using railroad right-of-way that encircled the CBD. According to Hamer (1976), the PBQ&D study paid no attention to alternative forms of rapid transit.

Atlanta's multi-county regional transit authority, Metropolitan Atlanta Regional Transit Authority (MARTA), was created in 1967, and six months after it came into being it hired PBTB, the consortium of engineering firms who planned and designed the BART system, to update the earlier work of PBQ&D. The consortium's plan, presented in a report to MARTA in September 1967, called for 65 miles of heavy rail with 40 stations. A truncated two-county 40.3 mile version of the rail system was subsequently proposed in a referendum in November 1968; it was decisively rejected by the voters. According to Hamer (1976, p. 156), however, "the actual causes of the referendum defeat appear to have little to do with the technical value of the plan."

* The discussion that follows of the planning efforts leading to the development of MARTA's rail plan draws heavily from Hamer (1976, pp. 145-48).

As a result of the decisive defeat of its rail proposal, the well publicized release of a proposal for a busway system by Atlanta's privately owned bus company Atlanta Transit System (ATS), and, more importantly, the requirement to prepare a comprehensive transportation plan to qualify for federal funds, MARTA agreed to help fund and participate in a comprehensive regional transportation study by A.M. Voorhees and Associates, begun at the end of 1967. The ATS proposal is the first of at least three bus rapid transit schemes that arguably would have been more cost-effective solutions to Atlanta's transit needs than the heavy rail system that was eventually built by MARTA. Before, we discuss the results of the Voorhees study, we first consider Rapid Busways, ATS's proposal to build an exclusive busway system for Atlanta.

ATS's Rapid Busway proposal, which in many respects resembles Ottawa's exclusive busway system described in Chapter 5, consisted of five radial express trunk lines that served as a core for 67 express routes. The Rapid Busway proposal, developed by Simpson and Curtin Engineers (1967) for ATS, provided a core of 23.3 miles of paved roadways (exclusive busways) in the right-of-ways of several railroads.* The authors of the Simpson and Curtin report (1967, p. 7) pointed out that, "population densities encountered in Atlanta are such that very few residents would be within walking distance of busway trunk lines or, similarly, rail rapid transit," and emphasized that the proposed busway scheme would have "750 route miles of rapid bus service converging on the 32.3 miles of busway trunk line." Almost one-half of the route miles were to be non-stop, at busway speeds of at least 45 miles per hour, and the remaining mileage was to serve local pickup areas.

Simpson and Curtin (1967) estimated it would cost $112 million (circa 1989 dollars) to convert the Atlanta's rail rights-of-way to rapid busway service, and provided the following brief description of its costing procedures.

> This preliminary estimate has been derived utilizing a typical BUSWAY cross section of two 12-foot bituminous lanes of pavement with three-foot stabilized shoulders making a total graded roadway of 30 feet. This cross section would be a minimum standard throughout the BUSWAY and construction costs, including a new 10-inch crushed stone base, asphalt paving, beam guard rail for 15 percent of the length and necessary grading averaging $587,000 per mile. New grade separations at locations where BUSWAY lines over pass surface streets average approximately $194 per square foot of structure. BUSWAY underpasses, including required excavation average approximately $291 per square foot (Simpson and Curtin, 1967, p. 19).**

No attempt was made to estimate the cost of required right-of-way, but the consultants argued these costs would be no greater than those projected for MARTA's proposed rail system, since the same rail rights-of-ways were to be used.

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* A discussion of the ATS proposal and the Simpson Curtin study is provided by Hamer (1976, pp 154-155).

** Unless otherwise noted, all dollar figures are in 1989 dollars. Construction costs are converted into 1989 dollars using the Engineering News Record Construction Cost Index. All other costs are adjusted into 1989 dollars using the GNP Implicit Price Deflator as an index.

Use of MARTA's right-of-way costs resulted in a total capital cost (construction plus right-of-way costs) for the ATS busway plan of $266 million in 1989 dollars. The authors of the Simpson and Curtin report thus concluded that the busway scheme, "would involve an initial expenditure of approximately 10 percent of the present estimated rail rapid transit costs," and that, "operating expenses for RAPID BUSWAY service could be sustained by the Atlanta Transit System" (ATS, p. 20). We have been unable to assess the cost estimates developed by Simpson and Curtin. Still, even if they were low by a factor of three or four, as they might well have been, the argument remains a powerful one.

The ATS busway proposal was one of five alternatives assessed by Voorhees and Associates in their 1969 draft report. The other four alternatives were: (a) a do-nothing, all-bus alternative, (b) a 66 mile rail transit system similar to the one proposed by MARTA in 1966, (c) a 66 mile system using a MARTA type high speed rail operation on a North-South route and a busway system for all other corridors, plus a northerly bus spur, and (d) a 65 mile system with 55 miles of exclusive busway and a 10 mile rail "distributor" running the North-South direction through the central area.

The draft report concluded that the system with 55 miles of exclusive busway and a short, i.e. 10 mile, rail distributor would best serve Atlanta's needs (Kain, 1972). Summarizing the finding of the draft report, Hamer (1976, p. 158) notes that this system would have "cost about one-quarter less than the MARTA plan," would have reduced per passenger trip costs by similar amounts, and would have carried about five percent more riders than the heavy rail system proposed by MARTA. Quoting from the draft report, Hamer (1976, p. 158) adds that, "busways with exceptions such as the distributor, would provide 'better overall service for every dollar invested in transit.' ... Capital costs favor buses for all but subway corridors, according to the report; and the patronage contemplated for Atlanta, operating costs would be equivalent." The draft report also found a "small busway system" had the lowest total cost per rider but rejected this alternative as doing "little for Atlanta's transportation problems" (Kain, 1972).

MARTA rejected the findings of the Voorhees report out-of-hand and brought pressure on the consultants to modify their findings and to support a heavy rail system (Kain, 1972 and Hamer, 1976). The final Voorhees reports included no transit plans, but in what Hamer (1976) refers to as "an about face," it grudgingly supports MARTA's 66 mile heavy rail system.

In commenting on the small busway, the final report boldly asserts: "construction of the small busway system would be a wasteful expenditure of funds because its capacity and performance is so limited that it would require costly rebuilding and modernization as soon as it is opened." Yet the final report provided no support for these assertions, and they seem inconsistent with analyses presented elsewhere in the same document (Hamer, 1976).

As Hamer (1976) points out, the alleged superiority of the large heavy rail transit system supported by the final report relied on questionable projections of CBD employment growth supplied by MARTA to their consultants (Hamer, 1976, pp. 148-54).* Even though these inflated CBD forecasts were used in the draft report as well, the Voorhees and Associates' recommendation was still for a system with a <u>54 mile</u> exclusive busway and only <u>10 miles</u> of heavy rail.

* As the recent use of overly optimistic CBD employment to justify a 92 mile LRT system for Dallas indicates, not much has changed in this regard (Kain, 1990).

Even though it rejected the draft report's recommendations, the final report concluded: "in the East-West transit corridor either rail or Busway could provide the needed express transit service and rail would attract nearly the same patronage as a Busway," and "given the initial Busway design standards assumed by AMV in this AATS study, Busway costs would be less than the costs for a similar rail line (emphasis added)." The AMV busways were overdesigned in ways similar to the busways assumed by Houston's METRO for its alternatives analysis: the draft report states that, "later more detailed engineering studies by MARTA, however, have indicated that the cost difference would not be obtained if their (MARTA's) preferred design standards, calling for greater right-of-way and additional construction were used (emphasis added)."

Hamer (1976) provides a detailed critique of the methods and assumptions used by MARTA to justify construction of its heavy rail system. Commenting on the discrepancy between Voorhees' draft and final reports, Hamer (1976) observes:

> The source of this about-face can be traced back to MARTA. The final decision to thwart the Voorhees team came in 1971 and was made official in April of that year. ... Voorhees is accused of underestimating the right-of-way and construction requirements of busways by omitting emergency lanes and central dividers. This objection is curious because the draft report notes quite specifically that all standards and criteria of the interested agencies are taken into account. The Voorhees team is also attacked for advocating the partial use of articulated buses, which is too daring for local officials who were later to consider BART's automated train controls for their rail system. Patronage projections quite suddenly became too low, the 1961 to 1983 growth forecasts being judged conservative (Hamer, 1976, pp. 158-59).

The third bus rapid transit scheme for Atlanta was proposed by Kain at a conference on Atlanta's transportation problems held at Georgia State University in 1972. Kain (1972b) suggested that "Freeway Rapid Transit" was, "the most promising rapid transit concept for Atlanta," and argued that a freeway rapid transit system could be built within a very short period of time for a capital cost of between one-fifteenth and one-one hundredth of the cost of MARTA's proposed heavy rail system.

Kain's Freeway Rapid Transit system would have used ramp meters and bus bypass ramps (similar to those described in Chapter 9 for Los Angeles) to insure express bus operating speeds of 50 mph or more. In this regard, the system envisioned by Kain for Atlanta would have operated in much the same way as the Shirley Highway, the El Monte Busway, and Houston's transitways, with the difference that it would have been necessary to keep vehicle volumes for the entire freeway at levels that would have insured minimum 50 mph speeds at all times. As we discuss in the next chapter, such a scheme would have undoubtedly encountered formidable enforcement problems and would almost certainly have had a lower benefit-cost ratio than the freeway HOV schemes that have emerged as the preferred approach to providing bus rapid transit operations in recent years.

Relying on estimates prepared by Stover and Glennon (1969), Kain (1972b) suggested a "bare bones" system that he argued could be implemented for a capital expenditure of about $17.8 million (in 1989 dollars). The required freeway surveillance system would have cost an additional $10.5 million (1989 dollars). Kain pointed out that the nearly $3.28 billion (in 1989

dollars) saved by implementing the Freeway Rapid Transit system instead of MARTA's proposed heavy rail system could be used for other purposes, and, in particular, suggested using the capital cost savings for an endowment to pay for lower fares and service improvements (Kain 1972b, p. 48). As an example, he calculated that use of two-thirds of the annual income from this endowment to reduce fares would increase 1983 transit ridership from 359,000 per day to 479,000 per day.*

Ottawa and Pittsburgh: A Different View

As we discussed more fully in Chapters 5 and 6, planners in Ottawa and in Pittsburgh, the only two cities in North American with exclusive busways, have reached conclusions different than those made by rail transit advocates about the relative cost-effectiveness of exclusive busways and light rail systems. Their views are based on both actual experience with exclusive busways and on studies done prior to the time a decision was made to build the busways.

As we discussed in Chapter 5, Ottawa completed a technology assessment (alternatives analysis) to determine the relative merits for Ottawa of building a bus rapid transit system based on a network of exclusive busways or a "comparable" light rail system. Consultants to the regional municipality and regional transit authority (OC Transpo) found that the overall capital cost of a comparable busway system would be only 68 percent as large as the cost of a comparable light rail system (Bonsall, 1987, p. 4). System costs included the total costs of both rapid transit service and the balance of services (principally bus services) that would have been provided by OC Transpo, Ottawa's transit authority.

Somewhat surprisingly, given the frequent claims about the operating cost advantages of LRT relative to buses, the Ottawa study also found that the annual operating costs of the all-bus system would be only 82 percent as large as the annual operating costs of the LRT-bus alternative.** Ottawa's operating cost comparisons, it should be emphasized, refer to the entire system; this contrasts with the all too frequent comparisons of LRT and bus relative operating costs, which compare the operating costs of the LRT services to the <u>average</u> cost of a system's or area's <u>entire</u> bus services.

As Gomez-Ibanez (1985) shows in his careful evaluation of the new San Diego, Edmonton, and Calgary LRT systems, comparisons of LRT operating costs to "average" bus system operating costs are not a valid way of assessing the relative cost-effectiveness of the two modes. He finds that the operating costs of San Diego's LRT were $1.24 per revenue passenger (1989 dollars) in fiscal 1983, or 43 percent <u>less</u> than the "average" operating costs per revenue pas-

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* In an after the fact analysis prepared for Houston METRO's "Rail Research Study," Kain (1989) found that MARTA's total transit ridership would have been 6.4 percent higher during 1980-88 if it had simply kept fares at the same level as 1979 in real terms instead of building its $2.5 billion (in 1989 dollars) rail system. The cost of this measure, i.e. no increase in fares in real terms, would have been 58 percent of MARTA's debt service over the same period. MARTA's debt, which was about $611 million (1989 dollars) in 1988, was largely incurred to pay the one-fourth of rail system capital cost paid by MARTA. The rest was paid by the Federal Government.

** Calgary, Canada apparently reached somewhat different conclusions in its alternatives analysis. A promotional brochure published by the City of Calgary Transportation Department states, "A busway system, like the LRT, would be slightly less expensive to construct. However, detailed studies have shown that <u>operating costs would be nearly double those of Light Rail Transit</u>" (emphasis added). We have been unable to obtain copies of the detailed studies and thus cannot meaningful assess them.

senger of all San Diego bus routes. Widely used comparisons, such as these, undoubtedly are responsible for the widely held view that LRT invariably provides large operating cost savings, relative to bus systems.* As Gomez-Ibanez (1985) points out, however, such comparisons are invalid because they compare the costs of serving the system's most heavily traveled route (new heavy rail and LRT lines invariably replace the most heavily used bus routes in any system) to the average cost of serving both heavy and very lightly traveled routes, including the bus feeders for the LRT system.

Gomez-Ibanez corrects this conceptual error by comparing actual LRT costs to hypothetical bus costs for the routes the LRT replaced. Comparisons based on fiscal 1984 data indicate that the operating costs of "hypothetical" bus lines serving the same riders who use San Diego's LRT would be 20 percent less than LRT operating costs, \$0.97 for "comparable" bus service versus \$1.21 for LRT All figures are in 1989 dollars). When capital costs are included, the comparisons, not surprisingly, are even less favorable to LRT. Gomez-Ibanez estimates capital costs for the bus system that would be required to replace the San Diego LRT would have been \$0.38 per revenue passenger as compared to the \$2.32 per revenue passenger capital cost for the LRT (both figures are in 1989 dollars). Total costs per revenue passenger of using bus to serve the routes currently being served by the LRT are thus only 38 percent as large as LRT costs per revenue passenger, \$1.35 for bus versus \$3.53 for LRT.

Bonsall (1987, p. 5) explains that the lower operating costs obtained for Ottawa's busway alternative "occurred primarily because of its closer demand/capacity relationship and the saving from interlining of the buses between routes on the busway system." He adds that passenger demand in most corridors varies with distance, and that it is much more difficult to short turn trains and to make other adjustments to match demand and capacity than with the bus system.

Bonsall's (1987, p. 6) overall assessment of the relative merits of the busway alternative selected by Ottawa and the competing LRT was that: "busway technology was selected ..., because the study showed it was cheaper to build, and cheaper to operate, it offered a higher level of service, greater staging flexibility, it met the capacity requirement of 15,000 passengers per hour in the peak direction, and was no different than the rail option as far as environmental impact was concerned."

Pittsburgh's PAT (The Port Authority of Allegheny County) is the only other North American transit system that owns and operates an exclusive busway. PAT's views on the relative merits of LRT and busway are all the more pertinent because PAT also owns and operates a modern LRT system. As we discuss in Chapter 6, PAT's new 10.5 mile LRT system replaced a portion of an aging street car system, all that remained of an extensive street car network that served the city in the period before World War II.

PAT's Director of Planning and Business Development, Alan D. Biehler (1988, p. 1), recently wrote a highly provocative paper in which he concluded that "sufficient evidence exists

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* The other source of the nearly unquestioned belief that busway or light rail operating costs are lower than bus costs is the observation, found in every document arguing for a costly rail system, that a single, multi-car train, with one driver can carry x times as many passengers as a single bus with one driver, where x depends on whether the comparison is light or heavy rail and on the train length assumed for the system. This correct, but highly misleading, observation ignores the much larger quantities of non-operating labor required by rail transit systems.

to conclude that busways offer an advantage over light rail for many applications, due to their attractiveness to riders, cost effectiveness, and flexibility."* Biehler's conclusions are based first on Pittsburgh's experience and second on ridership and cost data for other modern LRT systems. To quote Biehler:

> The recent investments and operating experience of San Diego, Pittsburgh, Portland, Buffalo and Sacramento provide the transit industry with new information about fixed guideways. In nearly all areas of comparison, busways appear to offer advantages over light rail systems.
>
> Experience of the past few years has shown that busways carry as many riders as do light rail systems. Because busways can be shorter in length yet still provide a good level of service, they carry more riders per mile of guideway.
>
> The operating cost advantage is such that busways cost less than half as much per passenger to operate than light rail. On the capital side, the averages presented in this paper show that an $80 million busway carries as many riders as a $310 million light rail system.
>
> The capacity of busways is sufficiently large to carry the expected ridership in the great majority of urban corridors. And, on the basis of their expected level of ridership, busways are as attractive to potential development as light rail.
>
> In addition, busways and bus systems are simpler to operate and maintain, and training requirements are less in comparison to light rail. Finally, busways provide greater operational flexibility than light rail, particularly in the ability to skip stops or to not stop at any stations along the busway if the passenger demand warrants. Express and local services can be better tailored to suit patron requirements (1988, pp. 96-97).

Biehler's findings rely on the comparisons of capital cost, operating cost, and ridership data for five modern LRT systems, including Pittsburgh's, and for Pittsburgh's two exclusive busways shown in Table 14-3. The figures for capital cost per trip and total cost per trip were not included in Biehler's paper, but were calculated by the authors from data that were.

Biehler's operating cost figures are limited to guideway operations for all seven systems, i.e. they excluded feeder bus operating costs for both the busway and the LRT systems.** Operating costs per trip for the five LRT systems studied by Biehler vary from a low of $0.97 per trip for San Diego to a high of $1.68 per trip for Sacramento (1989 dollars). Average operating costs per trip for the two busways, $0.47 and $0.61 (1989 dollars), are only 41 percent as high as mean operating costs per trip for the five new LRT systems. Operating costs per trip for Pitts

* Biehler's views, are contained in a paper he prepared for the TRB National Conference on Light Rail Transit held in San Jose, California in May 1988. They agree with the opinions of several PAT staff and officials we talked to in the course of completing this study. The consensus among PAT staff seems to be that, if they had to do it over again, and, if it was their choice to make, they would build three busways rather than two busways and one modern LRT system.

** It is impossible to be certain without detailed analyses, but it seems likely that this assumption works to the disadvantage of the busways.

Table 14–3. Comparisons of Recent Light Rail and Busway Systems
(All Dollar Figures Are in 1989 Dollars)

System	System Length (miles)	Capital Cost (Millions)	Weekday Ridership	Ridership per mile	Capital Costs/ Mile (Millions)	Capital Costs/ Trip (Dollars)	Cost per Trip Operating	Cost per Trip Total
Light Rail								
Buffalo	6.4	$565	30,000	4,700	$88	$6.28	$1.27	$7.55
Pittsburgh	10.5	$523	18,000	1,700	$50	$9.69	$1.63	$11.31
Portland	15.1	$233	19,000	1,300	$15	$4.09	$1.03	$5.12
Sacramento	18.1	$184	14,000	800	$10	$4.38	$1.68	$6.06
San Diego	20.4	$183	27,000	1,300	$9	$2.26	$0.97	$3.23
Average	14.1	$338	21,600	1,960	$35	$5.34	$1.31	$6.65
Busway								
Pittsburgh East	6.8	$138	29,000	4,300	$20	$1.59	$0.47	$2.05
Pittsburgh South	4	$38	18,000	4,500	$9	$0.70	$0.61	$1.30
Average	5.4	$88	23,500	4,400	$15	$1.14	$0.54	$1.68

Source: Allen D. Biehler, 'The Great Debate: Exclusive Busway versus Light Rail -- A Comparison of New Fixed Guideways,' TRB National Conference on Light Rail Transit, San Jose California, May 8–11, 1988.

burgh's two busways, moreover, are about half as large as operating costs per trip for its new LRT system.

Comparisons of total cost per trip are, not surprisingly, even less favorable to LRT. Total cost per trip averages $1.68 for Pittsburgh's two busways, as contrasted with $11.31 per trip for Pittsburgh's new LRT, and $6.65 for all five LRT systems (all figures are in 1989 dollars). Thus, according to Biehler's figures, the total cost per trip of Pittsburgh's busways are only 16 percent as large as for its new LRT system and only 28 percent as large as the average of the five new LRT systems in Table 14-3.

The much lower capital and total cost per trip for Pittsburgh's two busways relative to the five LRT systems is explained by the generally lower cost per mile of the busways, $15 million per mile for the busways versus $35 million per mile for the five LRT systems (1989 dollars), and by the fact that the busways are less than half as long as the LRT lines, 5.4 miles versus 14.3 miles. The shorter length of the busways is no accident. Exclusive or shared busways (discussed in the next chapter) are required only when buses would experience serious congestion from using general purpose roads and streets. In most situations, surprisingly short stretches of exclusive or congestion controlled, shared bus-HOV facilities are sufficient to permit buses to avoid the most serious congestion. Bus rapid transit systems require only as much exclusive or congestion free shared capacity as is required to bypass serious congestion. LRT systems, in contrast, since they cannot operate off their guideway, must be significantly longer than an exclusive busway to provide comparable coverage.

The higher costs per trip of LRT systems might be justified if they produced large indirect benefits of other kinds. While references to such benefits are invariably used in efforts to justify costly rail systems, the magnitudes of most indirect benefits, i.e. reduced auto congestion, less pollution, and the like are more or less proportional to system ridership. As the ridership data in

Table 14-3 indicate, none of these systems carry many riders and there is very little to choose between the two busways and five LRT systems in terms of this measure.

Average daily ridership on the two busways, i.e. 23,500, slightly exceeds average daily ridership on the five LRT systems. Pittsburgh's East Busway, moreover, carries only one thousand fewer passengers per day than Buffalo's LRT, the most heavily used of the five LRT systems.* The San Diego and Sacramento LRT systems, moreover, are two and one half to three times as long as the East Busway and consist of two lines. An argument could easily be made, therefore, for using the combined ridership of Pittsburgh's East and South Busways in these comparisons. If this convention were followed, total ridership on Pittsburgh's 10.8 miles of exclusive busways, which is 47,000 a day, far exceeds that on any of the five LRT systems.

Projected versus Actual Performance of New Rail Systems

UMTA recently funded a careful study of the projected and actual performance of new federally funded rail systems (Pickrell, 1989). Pickrell's findings confirm previously available fragmentary evidence showing that the proponents of heavy and light rail systems have seriously overstated probable future ridership on these systems, while at the same time seriously underestimating both the operating and capital costs of the same proposed rail systems.

Exclusive busways were not included in Pickrell's study. It appears, however, that there has been some tendency to overestimate ridership for these systems as well, in part because they are often done as part of feasibility studies or alternatives analyses for rail systems. Pittsburgh's successful busways, for example, were built as low-cost "consolation prizes," when the federal government and the Governor refused to provide funding for locally preferred rail lines.

Table 14-4 presents summary data from the Pickrell report for four new heavy rail systems and four new light rail systems. The eight systems studied vary widely in terms of extent, cost, and ridership. In terms of miles of line, for example, they range from Washington D.C.'s 60.5 mile heavy rail system to Buffalo's 6.4 mile LRT. Washington's system is, not surprisingly, also the most costly of the eight with total capital costs of over $8 billion (1989 dollars); Sacramento's 18.3 mile, "no-frills" LRT system had the lowest capital cost of the eight, $192 million in 1989 dollars, which incidentally is only 2.4 percent of the cost of the still uncompleted Washington D.C. Metrorail system.

These data reveal that with the exception of Pittsburgh's LRT, the constant 1989 dollar capital costs of all eight new federally, funded rail systems were underestimated by amounts ranging from a mere 16 percent in the case of the Portland LRT to 83 percent in the case of the Washington, D.C. rail system. Pickrell (1989) has completed a careful analysis of the reasons for these overruns, as well as for the still larger overruns in current dollar projections.

* According to Pickrell (1989, p. 16), rail ridership figures for light rail lines in Buffalo, Portland, and Sacramento "include substantial numbers of passengers who travel within free or reduced fare zones in the downtown areas they serve. In Buffalo, for example, a 1987 survey of rail riders indicated that more than 20 % travelled within the downtown free-fare zone, while during the Niagara Frontier Transportation Authority's (NFTA) Fiscal Year 1989, fare-free riders within downtown plus those transferring to the light rail line from buses (who also board free) together represented nearly <u>half</u> of the line's total ridership."

Table 14–4. Characteristics of Light and Heavy Rail Systems (All Dollar Figures Are in 1989 Dollars)

Item	Heavy Rail Systems				Light Rail Systems			
	Washing–ton, D.C.	Atlanta	Balt–imore	Miami	Buffalo	Pitts–burgh	Port–land	Sacra–mento
Year Service Began	1976	1979	1983	1986	1986	1985	1986	1987
Length (miles)	60.5	26.8	7.6	21.0	6.4	10.5	15.1	18.3
Number of Lines	4	2	1	2	1	1	1	2
Number of Stations	60	26	9	20	14	13	24	28
Weekday Rail Boardings (thousands)								
Forecast	569.6	NA	103.0	239.9	92.0	90.5	42.5	112.0
Actual	411.6	179.1	42.6	35.4	29.2	30.6	19.7	43.3
Percent Actual/Forecast	72%	NA	41%	15%	32%	34%	46%	39%
Actual Per Mile (number)	6,803	6,683	5,605	1,686	4,563	2,914	1,305	2,366
Construction Cost (millions)								
Forecast	$4,460	$1,756	$820	$1,028	$487	$713	$175	$168
Actual	$8,122	$2,773	$1,314	$1,367	$736	$634	$271	$192
Percent Actual/Forecast	182%	158%	160%	133%	151%	89%	155%	114%
Percent Federal Govt.	67%	87%	79%	NA	79%	80%	83%	58%
Annual Operating Costs (millions)								
Forecast	$69.2	$13.8	NA	$27.7	$10.9	NA	$4.0	$8.0
Actual	$208.7	$42.1	$22.7	$39.1	$12.1	$8.5	$8.1	$7.2
Percent Actual/Forecast	302%	305%	NA	142%	112%	NA	153%	90%
Operating Cost Per Rail Passenger								
Forecast	$0.12	NA	NA	$0.12	$0.12	NA	$0.09	$0.07
Actual	$0.51	$0.23	$0.53	$1.11	$0.41	$0.28	$0.31	$0.17
Percent Actual/Forecast	417%	NA	NA	959%	351%	NA	329%	232%
Total Cost per Rail Rider								
Forecast	$3.49	$2.83	$2.08	$2.07	$1.39	$2.82	$1.73	$2.09
Actual	$7.68	$5.16	$13.35	$14.41	$11.71	$9.44	$4.50	$5.97
Percent Actual/Forecast	220%	182%	642%	697%	845%	334%	259%	286%

Source: Pickrell (1989).

In his analysis of current dollar cost overruns, Pickrell attempts to allocate the overruns to five categories: (1) scope changes, (2) unanticipated inflation, (3) delay in start date, (4) construction schedule changes, and (5) unexplained. Pickrell (1989, p. 37) finds "that very little if any of the substantial real cost overruns experienced in building most of these projects can be ascribed to expansions in scale between their planning and construction phases." Pickrell's analysis clearly indicates that costs of the eight new rail systems he studied were systematically, and perhaps intentionally, underestimated at the time the decision to build these systems was made.

The data in Table 14-4 indicate system planners have been even more prone to underestimate the operating costs of new rail systems. The largest underestimate of operating costs,

for the five systems with both forecast and actual operating cost figures, occurs for the widely acclaimed Atlanta Metro. MARTA, Atlanta's regional transit authority, projected that its proposed rail system would cost $13.8 million per year to operate; actual operating costs are $42.1 million, a difference of 205 percent (both figure are in 1989 dollars).

As the ridership data in Table 14-4 reveal, actual ridership for the seven rail systems in which Pickrell (1989) was able to obtain comparable forecast and actual figures has fallen short of projected levels. Pickrell went to great pains to make certain the projected ridership and actual ridership data were for comparable systems and years. In most cases, the ridership forecasts he used were obtained from the draft or final EIS for each project. In each case, he chose a forecast year that corresponded to the actual year in terms of time since completion. Where delays occurred, this practice typically worked to the advantage of the project planners, as the actual year used by Pickrell was typically later than the original forecast year. Pickrell's comparisons are clearly conservative because in most cases the "decision" to build these systems, or the vote "approving" construction of a rail system were typically based on earlier and higher ridership projections.*

The largest gap between projected and actual ridership occurs for the Miami system, where actual ridership was 15 percent of forecast. Pickrell does not provide ridership forecasts for the Atlanta (MARTA) system, but rail boardings for the Washington (WMATA) system were 72 percent of forecast levels. Actual ridership for Baltimore, the final heavy rail system included in the study, was only 41 percent of the projected level.

Patronage shortfalls for the four LRT systems fall within a narrower range. Those forecasting ridership for the Buffalo LRT did the poorest job; actual ridership is only 32 percent of projected ridership. Planners in Portland, where actual ridership was 46 percent of projected ridership, did the most "accurate" job in the four federally funded light rail systems included in the study.

Pickrell (1989) attempts to explain the errors in forecasting ridership in terms of errors in forecasting several of the key exogenous variables used in making the ridership forecasts. These variables included service area population, CBD employment, rail headways and operating speeds, rail fares, the extent of feeder bus operations, auto operating costs, and downtown parking costs. The results of these analyses are fairly complex and can only be briefly mentioned here.

Pickrell concluded that errors in forecasting the input (exogenous) variables, "explain less than half of the observed gap between predicted and actual weekday rail passengers, except in Buffalo (where errors in the input assumptions appear sufficient to account for the entire difference between forecast and actual rail ridership) and Portland." Finally, he states:

> In short, it appears that only rarely can an important share of the large differences between forecast and actual rail ridership be attributed to errors in projecting variables that served as inputs to the patronage forecasting process. Instead, these errors must have arisen from other less obvious sources, includ-

* See Kain (1990) for a discussion of the use and misuse of ridership forecasts by DART in its efforts to secure voter approval for its rail plans.

> ing the structure of the ridership forecasting models themselves, the way in which they were applied, or the misinterpretation of their numerical outputs during the planning process.* Whatever its exact sources, the consistent overestimation of future ridership on recent rail transit projects suggests that the levels of travel and related benefits currently provided by these substantial investments are generally far below those that originally led local planners and political officials to make them (Pickrell, 1989, p. 29).

The pronounced tendency of system planners to underestimate system capital and operating costs and at the same time to overestimate ridership had the predictable effect on forecast and actual total costs per trip shown in Table 14-4. Forecast total costs per trip for the eight light rail systems ranged between $1.39 to $3.49 per rail passenger; actual total costs per rail passenger for the same eight systems varied between $4.50 and $14.41 (both sets of figures are in 1989 dollars). Actual total cost per rider in constant 1989 dollars as a percentage of projected total cost per rider ranged from a low of 182 percent in the Atlanta system to a high of 845 percent for the Buffalo system. Washington with actual costs per rider in excess of twice projected costs ranks second-best using this measure and Miami with actual costs per rider that are more than six times projected costs per rider ranks second worst.

Pickrell's findings concerning the pronounced tendency of rail system planners to under-project system cost and over-project system ridership do not in themselves directly prove anything about the relative cost-effectiveness of exclusive busways and rail systems. They are relevant, however, for at least three reasons. First, there is considerable circumstantial evidence from individual studies that system planners typically use optimistic assumptions when they develop rail system costs, and the data in Table 14-4 clearly support this view. Second, as we have discussed in both this and earlier chapters, there is substantial evidence that rail system planners frequently "gold-plate" exclusive busways to make their costs appear higher than they actually would have to be. Finally, overprediction of future ridership biases system choices towards rail systems, even if bus ridership is overpredicted by equivalent amounts. In most, if not all, alternatives analyses overly optimistic forecasts of future transit use favor rail alternatives because of their generally higher capital costs and because advocates of expensive rail systems often rely on a variety of ad hoc arguments to justify their construction. One of the most common and most effective of these ad hoc arguments, which we explained in Chapter 11, is the "inability" of central area streets to accommodate the huge projected numbers of buses. The large number of buses projected to use CBD streets in some future year is, of course, a result of overly optimistic projections of transit ridership.

Guided Busways

In March 1986, the first 4.2 miles of a 7.5 mile guided busway began operating in Adelaide, Australia. Using technology developed by Daimler-Benz A.G. and Ed Zublin A.G., the guided bus system, named the O-Bahn Busway by its developers, permits conventional buses, equipped with guide rollers, to operate on both regular streets and roads and on a special

* Errors arising from the way in which these models were applied, such as the design and coding of transit networks, are extremely difficult to detect, yet they may be a major source of the ridership forecasting errors documented by Pickrell (1989).

guideway equipped with a track which guides the buses while they are on the guideway (See Figures 14-3 and 14-4).

The O-Bahn system thus retains the technological advantages of conventional bus rapid transit, especially the ability of its vehicles to operate on city streets and roads, and at the same time it achieves most, if not all, of the advantages that have been claimed for LRT systems. Indeed, Wilson and Wayte (1988) contend the "O-Bahn" system eliminates virtually all of the objections to conventional busways. They claim the O-Bahn system:

- Requires the same right-of-way width as light rail.
- Has lower noise levels than a conventional busway and levels that are comparable to light rail.
- Provides a "quality of ride" that is equal to light rail.
- Can safely be operated at speeds equal to or greater than modern LRT systems.

Wilson and Wayte (1988, p. 2) also compare the Guided Busway to LRT, arguing that in the Adelaide application at least:

- Initial capital costs were significantly less than the competing light rail option.

Figure 14-3. Track Cross-Section for Guided Bus

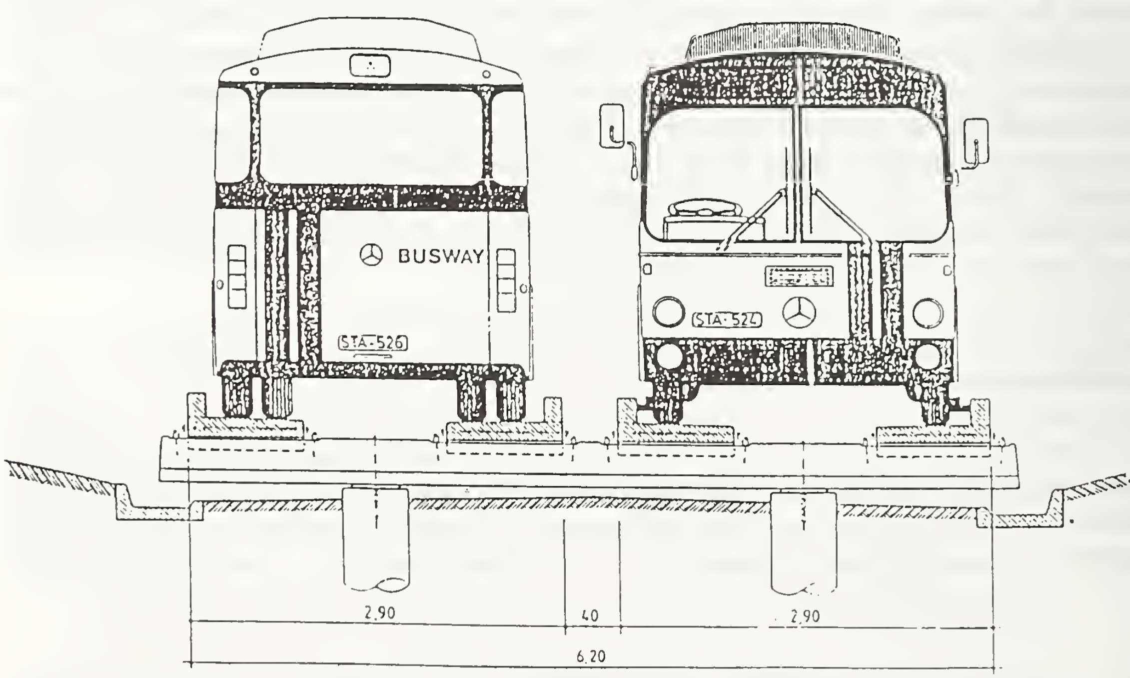
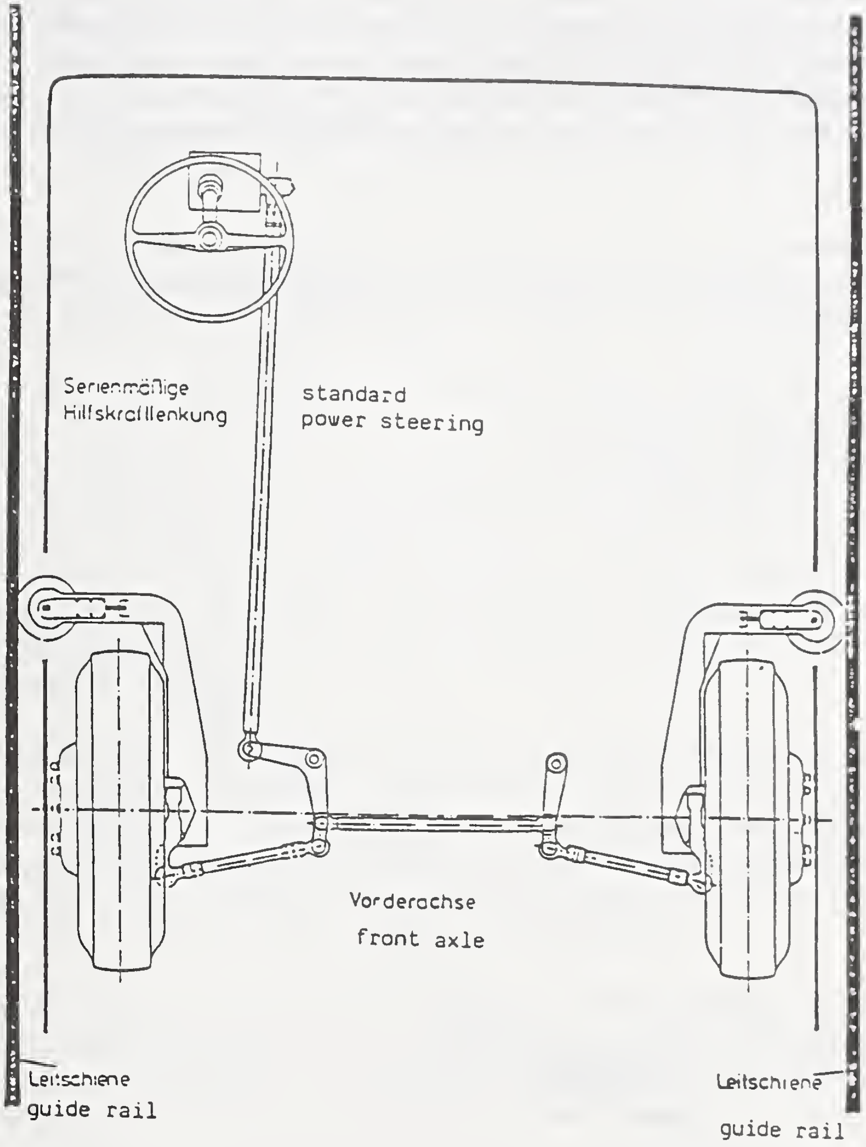


Figure 14-4. Mechanically Controlled Guidance System Used for Guided Bus System



- The system's potential capacity will be at least as large as that of LRT and in excess of likely future demand.

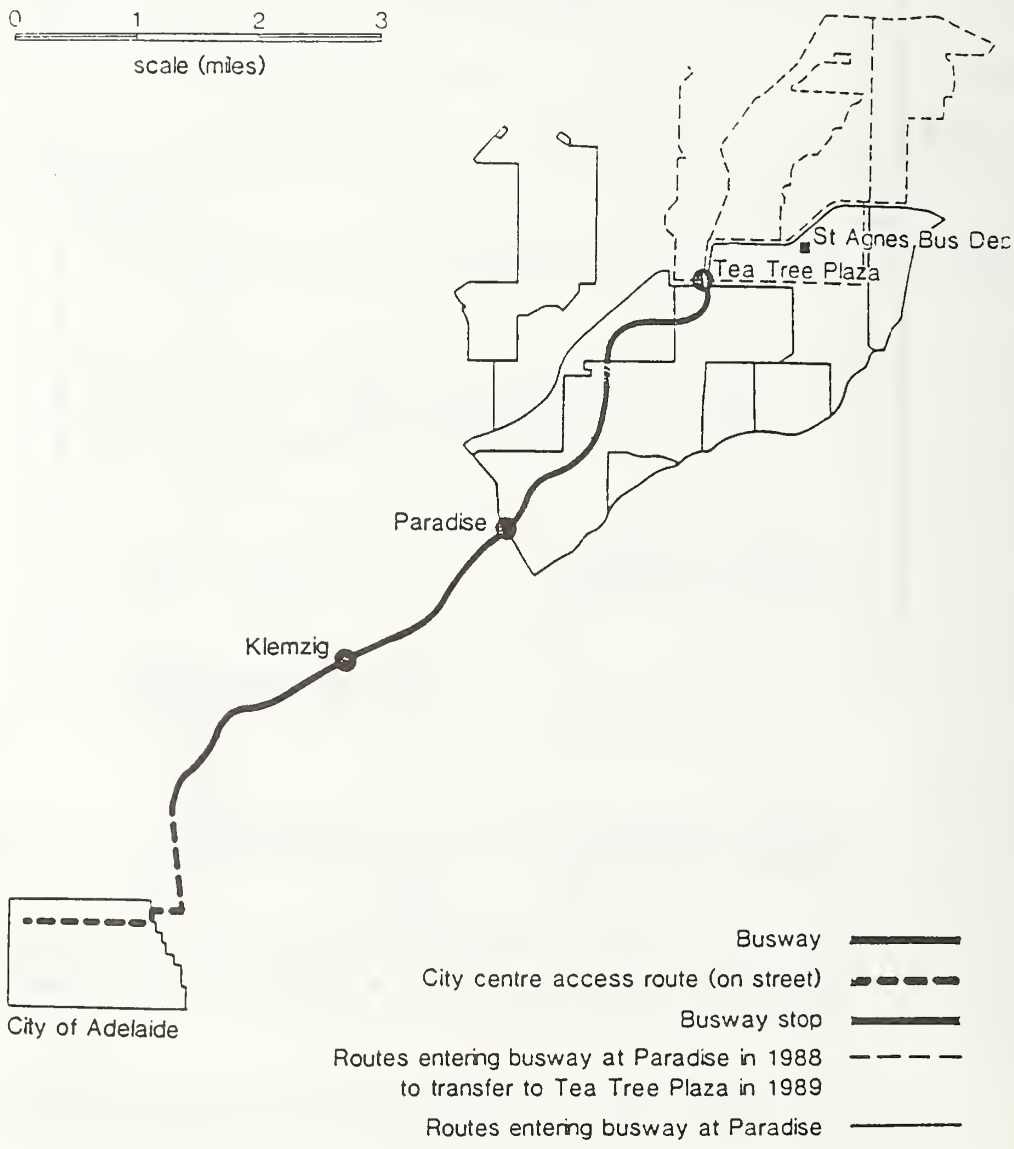
- Fewer transfers would be required for the guided busway system than for LRT because, like conventional bus rapid transit, the same vehicle may perform both feeder and line haul operations.

- No new costly and disruptive construction was required in the CBD as the buses are able to use the existing CBD street network for collection and distribution.

Door to door travel time for the guided bus system was generally less than for the LRT alternative because of the less frequent need for transfers.

The 7.5 mile guided busway, shown in Figure 14-5, operates between the edge of the CBD and a regional center in the northeastern suburbs. The guideway, which will have three on-line stations when it is completed, is fully grade separated, and is designed for normal operating speeds of 62 mph. Buses use downtown streets to distribute passengers within the central area.

Figure 14-5. Guided Busway System of Adelaide, Australia



The guided busway system replaced a conventional bus system which carried 12,000 passengers a day on 10 limited-stop, radial bus routes (when the entire guideway is completed the number of routes will increase to 13). Before the guideway was opened, passengers using these limited-stop services saved approximately 10 minutes relative to parallel all-stops services. These 10 bus routes, which have been rerouted to use the busway, currently use suburban streets for about 55 percent of their mileage, the guideway for 30 percent, and city streets for the remaining 15 percent. For some routes the guideway share of the total trip distance will increase from 30 to 60 percent when the busway is completed in 1989 (Wilson and Wayte, 1988).

Because of the relatively high speeds previously obtained by the limited-stop services, the fact that some buses have to travel somewhat longer distances to use the busway, and the fact that the first stage is only 4.2 miles long, only modest travel time savings have been achieved thus far, one or two minutes per trip on average. At the same time, the busway services are much more reliable and Wilson and Wayte (1988) report that, "many survey respondents cite travel time reductions as a prime motive for using the Busway." They add that, "passengers have been attracted to the Busway partly because of real improvements such as greater comfort and ease of access and partly due to a perceived difference and improvement compared the previous bus system." When the system is completed, it is expected that it will significantly decrease travel times for about half the passengers traveling beyond the guideways last station (Tea Tree Plaza). Peak period travel times from Tea Tree Plaza averaged 33 minutes before the Busway was opened, they are expected to average 23 minutes in 1989, when the full 7.5 miles of busway are completed.

During peak hours, buses operate through services from the various outer suburban route terminals to the CBD. In addition to the guideway services, several other city, local, and crosstown bus routes make connections at the stations. During peak hours, headways on the street section of the bus routes are about 10 minutes and on the busway itself about one minute. During periods of low demand, some of the suburban routes operate as feeders to the stations and frequencies on the guideway are reduced to five minute headways.

All the stations provide free parking, but 80 percent of all passengers board the buses while they are operating on the street. Even so, the demand for parking has exceeded expectations. The initial design provided for 175 park and ride spaces at the two first stage stations; this number has been increased to over 500, but still does not meet demand.

At the planning stage, consideration was given to a design that would have incorporated on-guideway stops. This alternative design would have avoided the breaks in the guideway included in the current system and would have allowed for high platform loading. In the end, system planners determined that the benefits from providing on-guideway stations were more than offset by other advantages of the current design, particularly the ability for express buses to bypass local and loading buses at guideway stops. In the present system, the guideway ends at either side of each stop and buses operate on a four lane (two in each direction) normal bus roadway. The breaks in the guideway also provide points where disabled vehicles can be removed from the guideway.

At the present time all busway routes operate on the same CBD streets, a route that provides for maximum coverage. The use of a common route for all busway services has the advantage of providing the highest possible frequency of service for passengers using the

busway, although this advantage is somewhat reduced by a need to separate the highest density CBD bus stops because of high bus volumes and time required to board passengers. Wilson and Wayte (1988) report that "possibly the biggest user criticism of the Busway has been the time taken to load articulated buses through a single front door. Up to three minutes is common in the evening peak at the major City stop. With average busway headways of 53 seconds between 5:00 and 5:15 p.m. it is not difficult to see why all buses cannot use a common stop."

Planners in Adelaide are considering ways of improving boarding times, for example, by allowing entry by two or more doors. In addition, in September 1987, the transit authority began running a few peak hour buses to the Paradise interchange from a different CBD street. As we discuss in Chapter 11, other modifications, such as increasing the fraction of prepaid tickets or collecting fares at the suburban end of the trip in both the morning and evening, would also reduce bus loading times and increase the capacity of CBD bus stages.

Transport analysts in Adelaide seem to consider the guided bus system an unqualified success:

> Planning to improve access by public transport to the northeastern suburbs was a protracted and controversial exercise ... In contrast, once the decision was taken to construct a guided busway and incorporate that busway into a linear park, the construction and operation have proved to be virtually problem free: ridership has exceeded expectations, public acceptability has been high (Scrafton and Wayte, 1988, p. 19).

Wayte and Wilson (1988, p. 12) observe that users have benefited from the major increase in comfort and convenience provided by the guided bus system and patronage has responded accordingly, with a 40 percent increase in patrons since the opening of the first stage.

The first 4.2 miles of the planned 7.5 mile line has been operating for over two years and the rest of the line was scheduled to begin operations in mid 1989. Wilson (1988) reports that ridership in June 1988 averaged about 16,500 passengers per day at the "City Cordon" and about 21,000 trips per day on all busway routes. Wilson and Wayte (1988), moreover, contend these figures are larger than expected. Of course, such claims must be viewed with skepticism, because of the common practice in the planning and design of urban transport systems to prepare at least two, and in many instances more, sets of projections. When advocates of urban transport systems talk about ridership exceeding expectations, they are usually referring to projections prepared shortly before the system opened. These projections, which are used in developing schedules, are invariably much lower than projections made prior to or at the time the decision to build the system was reached.

While our knowledge of the Adelaide situation is limited, there is no evidence that this common practice was followed for the guided busway system. Wilson and Wayte (1988) report that Pak-Poy and Kneebone (circa 1981) estimated two-way ridership at the cordon would average 16,550 riders a day in 1986, on the assumption that the entire 7.5 mile line would be completed. When it became apparent in 1984 that the full 7.5 miles would not be completed by 1986, system planners prepared a revised estimate for the first stage. This projection, an

increase of 20 percent over 1984 levels or 14,400, was rejected by the transit operator as being too optimistic and a compromise figure of a 13 percent Increase or 13,560 daily round trips at the city cordon was used for planning purposes. Current projections are 18,900 riders per day at the cordon in 1989 (after the full line has opened) and 19,100 per day in 1991.

The most serious technical problem encountered in operating the O-Bahn system in Adelaide was damage to the guide rollers (See Figure 14-4) by accidental contact with curbs while operating on surface streets. While the manufacturers offer retractable rollers, the operator in Adelaide concluded that while roller damage does occur there, the rate does not justify the expense and maintenance problems associated with retractable rollers. In addition, the rate of damage has decreased as drivers have gained experience. In some residential streets, however, it was necessary to modify the vertical geometry at sharp gradient changes, such as surface drains for storm water, to prevent the guide rollers from hitting the road surface.

In discussing the capacity of the busway system, Scrafton and Wayte (1988) conclude that a minimum headway of about 20 seconds could be achieved with the system's current operating practices (no signals are provided and drivers are responsible for driving the buses as they would on normal roads). Use of an all articulated bus fleet would provide a capacity of about 20,000 passengers an hour. These capacities, which are more than enough for most applications could be increased by more extensive modifications, such as the use of higher capacity vehicles (double articulated or coupled buses), by allowing more standees, and by changes in operating practices such as operating buses in platoons (Kain, 1988b). The authors conclude that a "guided busway could be seen as a medium capacity system with the same capabilities normally expected from LRT systems.

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Chapter 15. Cost-Effectiveness of Shared Bus HOV Facilities

Introduction

Analyses presented in the previous chapter indicate that exclusive busways will generally be a more cost-effective way of providing high-performance rapid transit services than light or heavy rail in nearly all cities in North American where new rapid transit systems are currently being considered. This is particularly true for low-density, Sunbelt and western cities such as Dallas, Houston, Phoenix, Denver, and Seattle, all of which are actively planning rail systems. Analyses presented in this chapter indicate that express bus systems using shared, high-performance, general-purpose freeways or HOV lanes will usually be an even more cost-effective way of providing high performance transit in these cities.

Exclusive busways cost substantially less to build than light or heavy rail lines serving the same corridor, and, somewhat more surprisingly, have lower operating costs in many situations. Express buses do not have to stop at every line haul station, as nearly all rail systems must, and can often act as their own residential collectors. As a result, high performance bus systems, operating on exclusive, congestion free right-of-ways are generally able to provide a higher level of service than even high-performance light or heavy rail systems.*

The principal focus of this chapter is on the advantages and disadvantages of exclusive busways relative to bus rapid transit systems that share lanes and roadways with carpools and other high occupancy vehicles (HOV) lanes. These comparisons clearly indicate that, while there may be situations where an exclusive busway will be a better choice than a bus rapid transit system that relies on shared general purpose or HOV lanes, systems which permit transit vehicles to share the large capital cost of high-performance, grade-separated right-of-ways with other users have a formable advantage over either exclusive busways or light or heavy rail systems.

The discussion that follows starts with an examination of the demand/capacity balance of operational bus-HOV facilities. It then turns to a discussion of the per trip capital costs of shared bus-HOV facilities, exclusive busways, and recently constructed light and heavy rail systems. The chapter's final section compares bus-HOV facilities and new rail systems in terms of their success in attracting new transit users.

Demand and Capacity of Rapid Transit Facilities

Rail transit advocates frequently speak of the "efficiency" of rail rapid systems, citing the ability of each heavy rail line to carry 50,000 or more persons per hour, per direction, and point to the low operating costs for such systems at these high volume levels. The only problem with such arguments is that actual costs per rail passenger are a steeply decreasing function of the

* Of course, passing and express services can be provided by double tracking, an option that dramatically increases system capital costs. These costs are so great that rail rapid transit systems are almost never double tracked. These trade-offs are discussed in Meyer, Kain, and Wohl (1965, Chapter 9).

number of riders carried (see Chapter 14, Figure 14-2), and the number of peak hour passengers actually carried by most rail systems is only a fraction of theoretical capacity. As a result, most of the capacity of light and heavy rail systems is simply wasted, and when actual ridership is low, operating and capital costs per rider tend to be very large.

The experience of Miami's recently completed heavy rail system, as documented by Pickrell (1989, p. vii) and Table 16-4, although a somewhat extreme example, makes this point very clearly. Planners of the Miami rail system predicted that soon after it opened, it would carry about 240,000 trips per day, and that total costs per rail passenger would be $2.07 (1989 dollars).* Actual system ridership in 1988, however, was only 35,000 trips per day, and, at this dramatically lower ridership, actual total costs per rail passenger in 1988 were $14.41 (in 1989 dollars). Rumor has it that the cost of subsidizing rail operations was so great that Miami's transit authority has been forced to curtail its other services.

Previous chapters have described the development and operation of highly successful bus-carpool facilities in a number of metropolitan areas, including New York (Chapter 3), Washington, D.C. (Chapter 7), San Francisco-Oakland Bay Area (Chapter 4), Houston (Chapter 10), and Los Angeles (Chapter 8). While buses using these HOV facilities serve significant numbers of transit users, they also require only a small fraction of the capacity of these roadways. The 179 buses operating on Shirley Highway HOV lanes (the facility with the largest peak hour transit ridership of those shown) during the AM peak hour, for example, use less than 10 percent of the capacity of its two reversible HOV lanes. Even if the Shirley Highway was a one-lane facility, as most of those shown in Table 15-1 are, buses would still use only 19 percent of its capacity. Of the remaining 12 facilities, buses using the bus-carpool lane on San Francisco's US-101 (Marin County to the Golden Gate Bridge) use the largest fraction of available capacity, and they require only 10.3 percent.

The shares of HOV lane peak hour capacity required for bus operations, shown in Table 15-1, are calculated using the assumption that a one-lane bus-carpool facility can accommodate 1,500 PCUs (passenger car equivalents) per hour, and that a bus requires 1.6 times as much capacity as the average auto. The 1,500 PCUs per hour capacity figure, selected as a level that would assure reliable 55-60 mph operation for vehicles using these facilities, is intentionally conservative.

The transit ridership figures in Table 15-1 may seem modest to readers accustomed to seeing and hearing references to the capacities of light and heavy rail lines or to daily ridership numbers. They are not. In recent years, Cleveland's Shaker Heights line carried 4,400 peak hour/peak direction passengers; the much acclaimed San Diego LRT 1,920; Buffalo, 4,672; Pittsburgh's LRT, 4,896; Portland, 3,152; and Sacramento, 2,304 (CRA, 1988, p. 4-10; Pickrell, 1989, p. 15; Gomez-Ibanez, 1985, p. 339).

None of the recently constructed light or heavy rail systems, exclusive busways, or HOV facilities require more than a fraction of their peak hour capacity to accommodate current peak hour demand. In contrast to exclusive busways or light and heavy rail lines, where expensive

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* Unless otherwise noted, all dollar figures are in 1989 dollars. Construction costs are adjusted to 1989 dollars using the Engineering News Record Construction Cost Index. All other figures are adjusted using the GNP Implicit Price Deflator.

Table 15–1. Busway–HOV Peak Hour Capacity and Demand

Facility	Year	Person Trips	Transit Trips	Peak Hour Vehicles: Cap PCU	Peak Hour Vehicles: VP & Carpools	Peak Hour Vehicles: Buses	Demand/Capacity: Buses	Demand/Capacity: Total
Washington, D.C.								
Shirley Highway	1988	16,526	6,265	3,000	2,100	179	9.5%	80%
I–95	1988	7,153	1,470	1,500	1,474	42	4.5%	103%
I–66	1988	5,795	665	3,000	1,619	19	1.0%	55%
Los Angeles								
El Monte	1977	4,551	2,708	1,500	657	81	8.6%	52%
Houston								
North	1989	3,295	2,950	1,500	39	71	7.6%	10%
Katy	1989	3,732	1,655	1,500	838	44	4.7%	61%
Gulf	1989	1,927	830	1,500	494	24	2.6%	35%
Northwest	1989	1,947	570	1,500	649	15	1.6%	45%
Seattle								
Boston								
Southeast Xway	1977	4,175	2,124	1,500	695	54	5.8%	52%
Miami								
I–95	1977	3,809	352	1,500	1,613	10	1.1%	109%
Portland								
Banfield Freeway	1980	3,376	657	1,500	1,292	22	2.3%	88%
San Francisco								
U.S. 101	1976	4,608	3,686	1,500	385	97	10.3%	36%

Note: "CAP/PCU" (capacity per lane, per hour) is assumed to be 1,500 passenger car units (PCU's).
Buses require 1.6 times as much capacity as one passenger car, i.e. 1 bus = 1.6 PCU.
Source: CRA (1988), Table 1–4; This report, Tables 8–2, 8–3, and 8–4.

excess capacity must go unused, the extra capacity of bus-HOV facilities can be used by carpools, vanpools, and other high occupancy vehicles. If transit ridership increases, a larger fraction of the capacity of these facilities can be allocated to buses.

As the data in Table 15-1 indicate, the ability of bus-HOV facilities to share capacity with other users makes a big difference. In the case of the three Washington, D.C. (Northern Virginia) HOV facilities during the AM peak period, for example, total peak hour person trips are 2.6 times as great as peak hour transit person trips for the Shirley Highway, 4.9 times as great for I-95, and 8.7 times as great for I-66, which it may be recalled from Chapter 7 is the nation's only HOV-only Parkway.

Houston's North Freeway Transitway, with only 1.1 times as many total peak hour person trips as peak hour transit trips, has the smallest ratio of total person to transit trips of the HOV facilities listed in Table 15-1. The explanation, as we discuss in Chapter 10, is that Hous-

ton's METRO, concerned about safety of carpool operations, allows only buses and "authorized" vanpools to use the North Transitway. As Houston's first barrier separated transitway, the North Transitway is somewhat narrower and has less generous geometry than Houston's newer transitways. While METRO never expected to open the North Transitway to carpools, it has been studying the issues associated with carpool use, and it would not be surprising to learn that it has decided to open the transitway to carpools, perhaps after some retrofitting has been done to improve sight-lines and other design features.

The data in Table 15-1 also indicate that, even with extensive carpool use, all but two of the 13 bus-HOV facilities listed had a good deal of spare capacity at the time the trip-making data were collected. The two facilities, with excess demand, at the 1,500 PCU level, are I-95 in Northern Virginia and I-95 in Miami. As we discuss in Chapter 7, there is excess demand for the I-95 diamond lanes in Northern Virginia only because they are used illegally by large number of vehicles with less than three occupants. Even though the I-95 bus-HOV lane in Miami carried substantially more person trips than each general purpose freeway lane, it has been discontinued.

Bus-HOV Facility Capital Costs

Efforts to estimate the capital costs of HOV facilities encounter a number of difficult conceptual and estimation problems. The most serious of these problems arise from the fact that bus-HOV facilities are generally built within existing freeway right-of-ways, and thus entail joint capital costs with the general purpose freeway lanes. The most important of these joint costs are the costs of building or rebuilding overpasses and bridges.* In addition, most HOV facilities have been built as part of freeway renovation and widening projects. Space for many, if not most, of the HOV facilities described in this report was obtained, at least in part, by adopting lower design standards than prevailed when the facility was first built. Depending on the situation, wide, landscaped medians were replaced with concrete barriers, traffic lanes and shoulders were made narrower, and in some cases one of the shoulders was eliminated altogether. On the presumption that the earlier, more generous design standards had some justification in terms of lane capacity, safety, or aesthetics, there is obviously a cost associated with adopting lower ones. As a practical matter, the impacts of these changes on capacity and safety appear to have been small, in part because many of the original designs were very conservative, and in part because lower standards have generally been accompanied by much higher traffic volumes and lower freeway operating speeds.

One approach to dealing with both joint cost problems and the more subtle issues of lower design standards, is to compare the benefits from adding an actual or proposed HOV lane to the benefits from adding or subtracting a general purpose freeway lane. In this framework, the person capacity of an unrestricted general purpose traffic lane (assuming typical vehicle occupancy rates) is viewed as the opportunity cost of allocating a lane to exclusive bus and carpool use. Assuming a capacity of 1,800 autos per hour and 1.1 persons per car, the opportunity

* Meyer, Kain, and Wohl (1965, Chapter 9) provides a useful discussion of the determinants of highway construction costs. Also see Small, Winston, and Evans (1989).

cost of an HOV lane is 1,980 persons plus any additional construction costs that may arise from using the facility as an HOV facility rather than as a general traffic lane.*

As the peak hour person trip volumes in Table 15-1 make clear, all 13 bus-HOV facilities easily pass the 1,990 person trip threshold test. The facilities that come closest to failing are the Gulf and Northwest Transitways in Houston. As we discussed in Chapter 10 and in the footnote on Page 16-18 of the next chapter, these short segments of transitway have only been recently opened and pass through areas with relatively little congestion. METRO planners expect the use of these lanes will grow rapidly as additional segments are completed and as congestion in the adjacent freeway lanes gets worse. The experience of Houston's older transitways, the North and Katy, provides support for their claims.

Cost and Cost-Effectiveness

Ignoring issues of joint costs for the moment, Table 15-2 presents estimates of total construction costs, costs per mile, and costs per directional lane mile for 12 bus-HOV facilities, for the Ottawa and Pittsburgh exclusive busways, and average total and per mile capital costs for the four light and four heavy rail systems studied by Pickrell (1989). The first two rows in Table 15-2 give these data for the El Monte Busway and the Shirley Highway HOV lanes, two of the earliest and most successful bus-HOV facilities. Keeping in mind the possibility that joint HOV-freeway costs may not have been properly allocated, the cost per mile of building these facilities are remarkably similar, $10.0 million per mile for the 11 mile El Monte Busway, and $10.6 million per mile for the 12 mile Shirley Highway HOV lane (both in 1989 dollars). Having said this, it should be noted that the two HOV facilities are quite different in concept and in design.

As we discuss in greater detail in Chapters 7 and 8, the El Monte Busway is a one-lane, two-way facility, while the Shirley Highway HOV lanes are two-lane, one-way, reversible HOV lanes. Of the two facilities, the Shirley Highway HOV lanes are more heavily used, carrying an estimated 63,486 persons per day in buses, 3+ carpools, and vanpools, a level that is about 50 percent higher than daily usage of the El Monte Busway. The Shirley Highway is even more heavily used by transit users, at 28,140 trips per day it carries more than twice as many transit trips as the El Monte Busway.

The last two columns, labeled "Cost/Round Trip, Transit" and "Cost/Round Trip, Total" are in many respects the bottom line of this analysis. Daily round trips, i.e. person trips divided by two, are used in these unit cost calculations. The column labeled "Cost/Round Trip, Transit" indicates that the El Monte's 1989 dollar capital cost per transit round trip, for example, a daily commuter trip to and from work, at $16,896 is nearly twice as large as the same figure for the

* SCAG (1987, p. A.1) in an analysis of this sort estimates that a proposed HOV system would cost $363 million, compared to $266 million (1989 dollars) if the same highway lanes developed as incremental general purpose freeway lanes. A bit of arithmetic indicates SCAG analysts believe commuter lanes cost about 1.4 times as much as incremental general purpose traffic lanes. As we discuss in Chapter 9, commuter lanes are not physically segregated from the general traffic freeway lanes and are accessed from the general traffic lanes. Barrier separated facilities such as the Shirley Highway and the Houston transitways cost much more to construct. In contrast, a study by Ulberg (1987, pp. 1,2, and 14) of the cost-effectiveness of HOV lanes in the Seattle area assumes that a bus-carpool lane would cost only about 10 percent more to construct than an additional general purpose freeway lane. The same study found that the marginal net present value of the three facilities studied was on the order of $5200 to $630 per commuter per year (1989 dollars) and that the "marginal benefit/cost ratio" was greater than six for all cases.

Table 15–2. Facility Length, Construction Costs, Daily Ridership, and Costs per Mile and Per Round Trip for Bus–HOV Facilities, Exclusive Busways, and Light and Heavy Rail Systems (Dollar Figures in 1989 Dollars)

		Daily Person Trips		Construction Costs (Millions)			Cost/Round Trip	
Facility	Miles	Transit	Total	Total	Per Mile	Per Lane–Mile	Transit	Total
El Monte Busway	11.0	13,221	43,000	$109.6	$10.0	$5.0	$16,896	$5,195
Shirley Highway	12.0	28,140	63,486	$127.2	$10.6	$5.3	$9,215	$4,084
Houston Transitways								
Katy	13.0	5,436	17,188	$51.3	$3.9	$3.9	$19,252	$6,089
Gulf	15.5	3,293	6,554	$76.9	$5.0	$5.0	$47,606	$23,919
Southwest	13.8	NA	NA	$72.1	$5.2	$5.2	NA	NA
North	19.7	10,783	12,706	$116.8	$5.9	$5.9	$22,083	$18,740
Northwest	13.5	1,967	5,972	$82.8	$6.1	$6.1	$85,837	$28,272
Eastex	20.0	NA	NA	$142.6	$7.1	$7.1	NA	NA
Houston Operational	36.6	21,479	42,420	$235.4	$6.4	$6.4	$22,341	$11,312
Houston Total	95.5	21,479	42,420	$542.5	$5.7	$5.7	$51,495	$26,074
I–66, N. Va.	9.6	3,430	31,270	$180.0	$18.7	$4.7	$106,974	$11,734
Commuter Lanes								
I–95, N. Va.	6.0	5,670	27,630	$5.8	$1.0	$0.5	$2,092	$429
Rte 91 S. Cal.	8.0	NA	19,102	$0.2	$0.03	$0.03	NA	$24
Rte 55 S. Cal.	NA	NA	45,990	$0.4	$0.06	$0.06	NA	$19
Exclusive Busways								
Ottawa	12.8	200,000	200,000	$403.2	$31.5	$0.0	$4,110	$4,110
Pittsburgh	10.8	47,000	47,000	$178.9	$16.6	$0.0	$7,762	$7,762
New Rail Systems								
Avg. Heavy Rail	29.0	168,500	168,500	$3,459.7	$119.4	$58.5	$41,860	$41,860
Avg. Light Rail	12.6	23,475	23,475	$467.1	$37.1	$18.1	$40,565	$40,565

Source: METRO (1989a, 1989b); APTA (1987); Pickrell (1989); Biehler (1989).

Shirley Highway HOV lanes. Comparing this column to the column labeled "Cost/Round Trip, Total" once again demonstrates the advantage of being able to share costly right-of-way with non-transit vehicles.* In the case of the El Monte Busway, the cost per trip when both transit and carpools are included is only about a third as large as when the facilities full capital cost is charged to transit. In the case of the Shirley Highway, capital costs per rider are only 40 percent as large when carpools and vanpools are included.

* These calculations allocate capital cost according to person trips. Since buses use much less road space per passenger than carpools, there is an argument for allocating the capacity costs according to the share of capacity used by each. This would, of course, dramatically reduce the estimated capital costs per transit trip.

The next panel in Table 15-2 presents these same statistics for Houston's extensive transitway system.* Both daily total and daily transit ridership are substantially lower for METRO's four operational, but still incomplete, transitways than for either the El Monte Busway or the Shirley Highway HOV lanes. The Katy Transitway, which is open to carpools and vanpools, as well as buses, has the largest total ridership, 17,168 person trips per day. The North Transitway, which is restricted to buses and authorized vanpools, has the largest transit ridership by far, 10,783 per day, as compared to the 5,436 transit trips per day for the Katy Transitway. Daily use of the Gulf and Northwest Transitways, both of which are open to carpools, is much less than either the Katy or North. As we observed previously, however, critical segments of both facilities were still under construction at the time these ridership statistics were collected.** METRO planners expect use of the Gulf Transitway will increase substantially when additional segments, adjacent to more heavily congested freeway segments, are completed.

While the estimates of total construction costs for the Houston transitways shown in Table 15-2 refer to the entire 95 mile system, the costs used in estimating per trip construction costs include only operational segments.*** As the resulting estimates indicate, construction costs per trip, both transit and total, for the Katy Transitway are about the same as for the more mature El Monte Busway and 30-32 percent higher than the same figures for the Shirley Highway HOV lanes. Estimated costs per transit and total trip for the Gulf Freeway also compare favorably to those for the El Monte Busway and the Shirley Highway HOV lanes. The cost per transit trip is actually less than for the El Monte Busway, although more than for the Shirley Highway HOV lanes, and the cost per total trip is only 16 percent greater.

Comparison of construction costs per <u>transit</u> trip to construction cost per <u>total</u> trip for the North Transitway once again illustrates the benefit, in terms of cost sharing, of being able to share costly facilities with carpools. As these data indicate, construction costs per transit trip for the North Transitway are lower than the same figure for either the Katy or Gulf Transitways; are only 59 percent as large as for the El Monte Busway; and are only slightly higher than the cost for the Shirley Highway. When total transit trips are used as the divisor, however, capital costs per trip decline very little for the North Transitway, but by a large amount for the other bus-HOV facilities. Using this metric, construction costs per total trip for Katy Transitway are only 62 percent as large as for the North Transitway.

The advantage bus-HOV facilities have in sharing capital costs is even more evident in the case of I-66, the HOV Parkway between Northern Virginia and the District of Columbia. As we discuss in Chapter 7, both peak direction lanes of this four lane parkway are used as a bus and 3+ carpool facility during the morning and evening rush hours. The use of I-66 by buses,

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* While the construction cost figures shown combine actual construction costs for completed transitway segments and engineering cost estimates for uncompleted segments, they are likely to be quite accurate as METRO and the Texas State Department of Highways and Public Transportation (SDHPT) have considerable experience in building transitways. As the row labeled "Houston Oper" indicates, 36.6 miles of Houston's authorized 95.5 miles of transitways were operational at the time (April 1989) these cost data were prepared by METRO and a large part of the remaining miles were either being built or were under contract. All cost data are given in constant 1989 dollars.

** In the case of the Gulf Transitway, for example, only the first four miles were operational. This four mile segment was built, moreover, in conjunction with a major freeway widening project. As a result there is very little congestion in the adjacent freeway lanes and limited benefit from using it.

*** Since no direct estimates of these costs were available, we estimated them by assuming the proportion of total construction costs for the operational segments of each transitway is the same as operational miles are of total miles.

moreover, is quite limited. As data in Table 15-2 indicate, only 19 buses per hour use I-66 during the morning peak hour, and as the data in Table 15-1 indicate, these 19 buses serve only 3,430 transit trips.

If transit had to bear the entire cost of the I-66 Parkway, its 1989 dollar capital cost per daily round trip would be the almost $107,000 made in 1988, a figure that exceeds the per transit trip capital cost of any of the other bus-HOV facilities shown by a large amount. If all the capital costs are charged to peak period users, however, the cost per round trip declines to $11,734 (1989 dollars), and if total daily trips are used in the denominator, the construction cost per round trip plummets to $3,523, a figure that is lower than the total 1989 dollar per trip cost of any of the bus-HOV facilities shown in Table 15-2, except the three commuter lanes.

Costs per total trip for the three commuter lanes shown in Table 15-2 vary from a low of $19 per trip for California's Rte 55 commuter lane to $429 per daily trip for the I-95 commuter lane in Northern Virginia (both in 1989 dollars). Of the three, I-95 is the most costly by far, and is the only one with significant transit use. As we discuss in Chapter 7, the I-95 diamond lanes are 6 mile HOV lanes (both directions) that feed the Shirley Highway HOV lanes. When they were first opened, use of the I-95 diamond lanes was restricted to buses and 4+ carpools; in January 1989 the carpool criterion was changed to 3+, a development that appears to have had very little effect on lane usage.

As the construction cost data indicate, the I-95 diamond lane is dramatically cheaper both in terms of total cost per mile and in terms of cost per round trip than the El Monte Busway, the Shirley Highway, the transitways in Houston, or I-66. The 1989 dollar incremental capital cost of the I-95 diamond lanes was approximately one million dollars per mile, as contrasted to construction costs of $5.7 to $10.3 million per mile for the barrier separated facilities (1989 dollars). In terms of cost per total trip, I-95 cost $429 per round trip as compared to $5,195 for the El Monte Busway, $4,084 for the Shirley Highway HOV lanes, and $11,312 for Houston's 36.6 miles of operational transitways (all figures are in 1989 dollars).

The key word is "incremental." The $6.0 million cost in 1989 dollars of the I-95 diamond lanes, which are essentially interim, low-cost extensions of the Shirley Highway HOV lanes, is so small because Virginia DOT did little more than allow buses and 4+, subsequently 3+, carpools to use the median shoulders as travel lanes. The construction costs incurred in building the I-95 diamond lanes consisted of marking the roadway and building an emergency shoulder on the right hand side of the roadway, where no shoulder had existed previously.

The more significant costs of the I-95 diamond lanes are presumably the effects, if any, of using the median shoulder as an HOV lane on the capacity and safety of the general traffic lanes, and the aesthetic costs of converting the median shoulder to a bus and carpool lane and of building a new emergency shoulder on the right hand side the roadway. As we discussed previously, an alternative and commonly used approach to thinking about the cost of HOV facilities is to treat the benefits from using the same space for an ordinary general traffic lane during peak hours as the opportunity cost of providing an HOV lane. As the data for I-95 presented in Chapter 7 reveal, the inbound I-95 diamond lane serves 7,153 trips during the AM peak hour, as contrasted to 2,586 trips in each of the adjacent general traffic lanes.

The incremental costs of Southern California's commuter lanes are even less than those of Northern Virginia's I-95 HOV lane. According to Caltrans, the incremental cost of implementing the eight mile long Rte. 91 commuter lane in 1989 dollars was only $215,000, or a mere $26,800 per mile (Roper, 1986). As we discuss in Chapter 9, the 11 foot wide commuter lane was implemented by allowing buses and 2+ carpools to use the inner, median shoulder, and by reducing the width of the adjacent traffic lane from 12 to 11 feet.* Capital costs of the Rte. 55 commuter lane were presumably similar to those for Rte. 91. In Table 15-2, we assume the cost per lane mile was the same for Rte 55. To make room for the Rte. 55 commuter lane, Caltrans restriped all of the freeways general traffic lanes narrowing them from 12 to 11 feet. The new commuter lanes were then added on either side of the median.

Neither the Rte. 91 and Rte. 55 commuter lanes have much transit use; they are essentially 2+ carpool lanes.** In terms of the opportunity cost comparison to general traffic lanes suggested above, the Rte. 91 commuter lane served 3,190 persons during the morning peak hour in 1986, as compared to 2,200 persons per hour in each of the adjacent general traffic lanes. Similarly, 3,520 persons used the Rte 55 commuter lane during the PM peak hour, as contrasted to about 2,200 persons for each of the freeways general traffic lanes.

Shared Bus-HOV Facilities vs. Exclusive Busways

Table 15-2 also contains cost and ridership data for Ottawa's and Pittsburgh exclusive busways. In terms of total ridership, Ottawa's 12.8 mile, Phase I transitway system is in a league of its own. With 200,000 transit users a day, it dwarfs the Shirley Highway HOV lanes with 28,000 daily transit trips and 63,000 total trips, and Houston's still incomplete transitway system that carried a total of 21,479 transit trips and 42,000 total trips each day in 1988.***

Ottawa's exclusive busways also have the lowest capital cost per transit round trip at $4,110 (1989 dollars); the busway-HOV facility with the lowest cost shown in Table 15-2, the Shirley Highway HOV lanes, has a capital cost of $9,215 per transit round trip (1989 dollars). When construction cost per total round trip is used as the criterion, however, the Shirley Highway HOV lanes become $26 per total round trip cheaper than the Ottawa Exclusive Busways, $4,084 per round trip versus $4,110 (all figures are in 1989 dollars).

Pittsburgh's exclusive busways are nearly twice as expensive per transit trip and per total trip (these are the same for exclusive transitways) as Ottawa's exclusive busways. This is entirely due to Ottawa's much higher ridership. According to the data in Table 15-2, Ottawa's exclusive busways cost about twice as much to build per mile in 1989 dollars as Pittsburgh's,

* Table 3-2 of the Highway Capacity Manual provides adjustment factors for estimating the effects of restricted lane widths (lane narrower than 12 feet) and inadequate lateral clearance (median objects and barriers closer than six feet) on roadway capacity. The adjustment factors are used to estimate the effect of these lower standards on maximum service flow rate under ideal conditions for high performance urban expressways. For situations where the nearest barriers or obstructions are six or more feet from the traveled pavement, reducing lane width from 12 to 11 feet, reduces the capacity of each 11 foot lane by three percent. Similarly, a barrier on one side of the roadway located three feet from the roadway reduces per lane capacity by two percent, and if both conditions are present, capacity is reduced by five percent (Transport Research Board, 1985, p. 3-13).

** The principal exceptions are airport buses and vans.

*** Of course, the Ottawa Transitways serve the equivalent of two and possibly three corridors, while the El Monte Busway serve only one.

$31.5 million a mile versus $16.6 million a mile. When the comparison is limited to transit trips, the per round trip cost of the Pittsburgh busways is less than those of any of the shared bus-HOV facilities. When total daily round trips are used in the denominator, however, the per round trip costs are less for all of the mature shared bus-HOV facilities except Houston's North Transitway, which, of course, is very close to being an exclusive busway; only buses and "authorized" vanpools are allowed to use the North Transitway. Even so, the per trip costs of Pittsburgh's exclusive busways are only 50 percent more than those of the mature, bus-HOV facilities. While this may seem like a large difference at first glance, as the next section shows, it is rather small potatoes when it is compared to the capital costs per round trip of new light and heavy rail systems.

Bus-HOV Facilities vs. New Rail Systems

As the data on new light and heavy rail systems included in Table 15-2 demonstrate conclusively, the per round trip costs of light and heavy rail systems far exceed these same costs for both exclusive busways and shared bus-HOV facilities. With two exceptions, this result holds whether the comparison is in terms of transit trips or total trips. The data for new light and heavy rail systems in Table 15-2 are from Pickrell's (1989) careful study of forecast versus actual ridership and costs for new federally funded rail starts. The figures for heavy rail systems are weighted averages of the ridership and cost data for the four heavy rail systems (Washington, D.C.; Atlanta, Ga.; Baltimore, Md.; and Miami, Fla.), and similarly, the figures for light rail systems are weighted average for the four light rail systems (Buffalo, N.Y.; Pittsburgh, Pa.; Portland, Ore.; and Sacramento, Cal.), studied by Pickrell (1989).

As the data for heavy rail in Table 15-2 indicate, these systems are on average more than twice as long as the light rail systems, 29 miles vs. 12.6 miles, and have much higher daily ridership, 168,500 vs. 23,475. The heavy rail statistics, moreover, are clearly dominated by the 60.5 mile, $8.1 billion dollar Washington, D.C. system, and by the 26.8 mile, $2.8 billion dollar Atlanta system (both figures in 1989 dollars). By comparison, the other two heavy systems, Baltimore and Miami, are only 7.6 and 21 miles long respectively. The extent and cost of the four light rail systems are much more uniform; they vary in terms of length from 6.4 miles (Buffalo) to 18.3 miles (Sacramento), and in terms of 1989 dollar cost from $192 million (Sacramento) to $736 million (Buffalo).

In many respects the most surprising feature of Table 15-2 is how similar the average capital costs per daily transit round trip are for light and heavy rail systems. According to these data, the capital costs of heavy rail systems, which are $41,860 per daily round trip are only three percent greater than the same statistic for light rail systems, which is $40,565 per daily round trip (both figures in 1989 dollars). Much of the interest in light, as opposed to heavy rail, is grounded in the idea that light rail is cheap. These data on capital cost per daily rail round trip raise serious questions about the title, or at least the subtitle, of the conference volume from the recent (May 8-11, 1988) National Conference on Light Rail Transit. The volume's title is Light Rail Transit: New System Successes at Affordable Prices (National Research Council, 1989). As the data in Table 15-2 make clear, while the construction cost per city and per mile of light rail transit may be much less than the construction cost per city and per mile of heavy rail, there is almost no difference in the capital cost per daily transit round trip for recently completed light and heavy rail systems.

When construction costs per round trip for both light and heavy rail systems are compared to the same statistics for exclusive busways and shared, bus-HOV facilities, the situation is markedly different. Mean capital costs per transit round trip for the four light rail systems studied by Pickrell are five times as large as the capital cost per transit round trip for the Pittsburgh exclusive busways and nearly 10 times as large as for the Ottawa exclusive busways. If the capital cost per transit round trip of the four light rail systems are compared to the per trip costs of the several shared bus-HOV facilities, using total trips as the divisor, they are nearly eight times as expensive as the El Monte Busway, almost ten times as expensive as the Shirley Highway HOV lanes, nearly seven times as expensive as the Katy Transitway, more than six times as expensive as the first segment of the Gulf Transitway, and over twice as expensive as Houston's North Transitway. Even the partially completed Northwest Transitway in Houston fares well in this comparison, and METRO planners are confident that usage of the Northwest Transitway will increase dramatically when the current impediments to using the facility are eliminated. It would be hard to find anyone who would make the same argument for the four new light rail systems.

Exclusive Busways vs. Shared Bus-HOV Facilities

It is tempting to conclude from the data in Table 15-2 that it is always better to build shared, bus-HOV facilities than exclusive busways. As should be clear from a reading of the discussions of the Ottawa (Chapter 5) and Pittsburgh (Chapter 6) exclusive busways, however, such a conclusion would be premature. The exclusive busways in both Pittsburgh and Ottawa differ in important respects and serve rather different markets from the bus-HOV facilities in Washington, D.C., Southern California, Houston, and elsewhere.

Both the Ottawa and Pittsburgh busways have on-line stations and carry significant amounts of walk-on traffic. In this respect, they closely resemble many light and heavy rail systems. Both busways, however, are also used by large numbers of express bus routes that collect their passengers at park and ride lots or in suburban residential areas and use the busway for a fast non-stop trip to the central area. While it is possible to have on-line stations on a shared bus-HOV facility (the El Monte Busway has one, for example), the provision of on-line stops (stations) on shared bus-HOV facilities creates numerous engineering, safety, and operational problems. Overcoming these problems may significantly increase the capital costs. Where transit demand is sufficient to use a large fraction of an exclusive busways capacity as in Ottawa, or in the case of the South Busway in Pittsburgh, it may simply not be worth it to allow carpools and vanpools to use them.*

Successful exclusive busways are likely to be short and be located in built-up and fairly dense areas with relatively high levels of transit ridership. In such situations, exclusive busways may provide a superior service for existing transit riders in the corridor, as well as serve as a high speed right-of-way for express services from suburban residential areas. It should be understood, moreover, that the choice need not be all or nothing. A well designed, high-performance bus system might include both exclusive busways and shared, bus-HOV facilities.** Where an

* As we discuss in Chapter 6, Pittsburgh's South Busway has considerable excess capacity over much of its length, but it operates at close to capacity through the Mt. Washington Tunnel, where busways share the roadway with Pittsburgh's new South Hills LRT line and its aging South Hills streetcar system.

** Several members of the National Peer Review Group for Houston's METRO "Rail Research Study," and in a particular Herbert Levinson, urged METRO to investigate the possibility of building a North-South, exclusive busway linking the planned

extensive network of regional expressways already exists, as in most American cities, or is being built, as in many other countries throughout the world, it almost certainly makes sense to include a number of miles of shared, bus-HOV facility in the system design.

Within existing built-up areas, however, where densities are higher, and where there is a potential for walk-on ridership, exclusive busways may be the preferred solution, particularly if there exist, as is true in Pittsburgh as well as in many other cities, narrow underutilized or abandoned rights-of-way that are too narrow for a major highway, but have sufficient width for an exclusive busway or a light or heavy rail line.* In such situations, it may be desirable to build a busway and limit its use to buses, although it remains true that the cost per daily user could very likely be reduced by allowing vanpools and carpools to use the facility as well.

There is a practical dimension to the choice as well. Experience with exclusive busways built in freeway corridors is that they seldom remain exclusive busways. The El Monte Busway, the Shirley Highway HOV lanes, and the Katy Transitway all began their lives as exclusive busways, or in the case of the Katy Transitway as an exclusive bus and authorized vanpool facility. The reason is that auto drivers and passengers in the heavily congested, adjacent freeway lanes invariably become convinced that the busway is grossly underutilized, even if it is carrying many more passengers per hour than each general purpose highway lane. And in a sense they are correct. In such situations motorists invariably pressure policymakers to allow carpool use of their busway, and in most cases they prevail. The experience has been different for exclusive busways, and for that matter for rail systems, that do not share freeway right-of-ways. Motorists in heavily congested freeway lanes do not see this "excess capacity" each day, and, as a result, they have been much less prone to demand access to these facilities, even when the extent of excess capacity is as great or greater than for a freeway based exclusive busway.

Increases in Transit Ridership

Proponents of rail rapid transit systems rely heavily on extravagant projections of future ridership to justify the large capital costs of these systems. In fact, new rail rapid transit systems attract relatively few <u>new</u> riders. The reason is that they are typically built in corridors where they will attract the most riders <u>overall</u>; not surprisingly, these are generally well developed transit corridors where the new rapid transit line invariably replaces the city's most heavily traveled bus line or lines. There may be benefits from building new rail transit lines in such situations, but a large increase in the number of new transit passengers is not among them. Any growth in ridership that occurs would have to be due to reductions in door to door travel time, which in most instances are modest.**

Southwest Transitway, the Uptown/Galleria area, and the Katy, the North and Northwest Transitways, TTI (1989). METRO staff, however, was and has apparently long been resistant to such ideas; a north-south busway would largely eliminate the principal justification for building the light or heavy rail system METRO has had as its primary objective since its inception.

* The fact that busways can be often designed as one-way reversible facilities with buses using parallel streets, arterials, and freeways for trips in the off-peak direction makes it even more likely that a busway would be able to use a narrow right-of-way of this kind.

** These observations apply to a somewhat lesser extent to the exclusive busways in Pittsburgh and Ottawa (Chapters 5 and 6) as well. While these busways have reduced operating costs and have enabled PAT and OC Transpo to provide somewhat more reliable and faster service, the measurable short-run impact on ridership appears to have been small.

Transit authorities with new light and heavy rail systems have made little effort to make careful after the fact assessments of the impact their new rail systems on transit ridership. As we noted previously, however, the studies of new federally funded rail systems by the CBO (1988) and by Pickrell (1989) paint a rather bleak picture. The following quote from the CBO report (1988, p. 41), which suggest these systems principally act as costly replacements for lower cost bus routes, gives the flavor of its findings:

> For the most part, the new rapid rail systems took the place of existing bus service, but their failure to attract large numbers of new riders to fill the extra seats they offered stems chiefly from the effect of that switch on travel times and costs. To compete with autos, public transportation must be attractive in terms of convenience, time, and cost. ... The new rail systems may be less attractive to previous bus riders than the buses they replaced, and hence, as a corollary, are less likely to divert auto drivers to transit.

While the Pickrell (1989) and CBO (1988) studies indicate that actual ridership on new rail systems was much less than projected ridership, and that the investment of billions of dollars in rail transit systems did not increase aggregate transit ridership in these cities, they do not specifically answer the question of the effect of a particular rail line on transit ridership. Gomez-Ibanez (1985) has done an assessment of this kind for the early years of San Diego's new LRT system.

San Diego's so-called Tiajuana Trolley is an example of a recently built LRT that replaced heavily used bus lines. Gomez-Ibanez (1985, p. 340) in commenting on the San Diego experience notes that:

> LRT advocates often cite San Diego's experience to support their arguments that LRT can attract added patronage. During the first three years of trolley operation the trolley's patronage gains more than offset ridership losses on the replaced or competing north-south trunk bus routes and total transit ridership (bus and LRT) in the South Bay area increased by 22 percent... . The impressive gains in the South Bay are all the more impressive because transit ridership in the rest of the San Diego metropolitan area fell by 18 percent.

A closer examination of the increases in transit ridership attributed to San Diego's LRT, however, raises serious doubts about the extent to which the trolley itself was responsible for the growth in ridership. Gomez-Ibanez (1985, p. 340) found that other South Bay transit services, including several that have relatively few transfer passengers with the trolley, had similar percentage increases, and that the trolley worsened service for many South Bay riders. Tourists, moreover, accounted for half of the increase in ridership.

As we have indicated previously, the El Monte Busway, the Shirley Highway, and the North Contra-flow lane in Houston had much larger impacts on transit ridership than appears to have been true for new rail systems. The following indicates the extent of transit ridership growth for these facilities in the first 2-3 years after they opened.

> AM peak period bus ridership on the Shirley Highway (Chapter 7) increased from 3,800 when the busway first opened to 4,500 in 1970, to 9,000 by 1971, to

13,500 in 1973, and to over 16,000 in November 1974. The current (May 1988) level, which is 14,000, is somewhat below the 1974 level.

- Transit ridership on the El Monte Busway (Chapter 8) increased from 2,000 trips per day (17 hours, both directions) to 10,000 trips per day in March 1975. Bus ridership reached its peak in 1976 just before the first section of the busway was opened to carpools.

- In the first 33 months of North Freeway Contraflow lane operations in Houston (Chapter 10), average AM peak period bus ridership grew by 1,600 percent, from 265 passengers per day immediately prior to the beginning of contraflow operation in August 1979 to over 4,500 in May 1982.

There are four principal reasons why the above listed busways induced far more growth in transit ridership than most new rail systems have. First, in each case the facilities provided large travel time savings relative to the situation that existed before they were implemented. The net effect of new rail systems on door to door travel times and other dimensions of service quality have been far more problematic. Second, each was implemented in a rapidly growing and heavily congested corridor. Third, in contrast to most new rail systems, which have been constructed in existing well developed transit corridors, the three busways referred to above and most bus-HOV facilities have been designed to serve new transit markets. Finally, the implementation of the busway was typically accompanied by a major expansion in transit service levels and by the provision of transit service to areas that were unserved previously.*

* Even so, the time savings provided by these facilities also were an important factor in increasing transit use. In the case of Houston's North Freeway contraflow lane, AM peak period ridership for February 1981 averaged about 3,200; Atherton and Eder (1982, p. 6-19) estimate that without the contraflow lane and the same level of transit service, ridership would have been in the range 1,379 to 2,066.

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Chapter 16. Alternative Approaches to Sharing Roadway Capacity

Introduction

Analyses presented in the previous chapter indicate that transit systems that rely principally on shared, congestion controlled, grade-separated facilities to achieve dependable and high speed transit services have a formable capital cost advantage in most low-moderate density areas over exclusive busways and light and heavy rail systems that cannot share their excess peak hour capacity with other users. Assuming, for the moment that this argument is correct, two issues remain. What is the best way of achieving and maintaining the congestion free conditions required for dependent high-speed transit operations, and how large an effect do the time savings provided by HOV lanes or other bus-carpool priority schemes have on transit use and carpooling?

As we discuss below, whether the time savings provided by HOV lanes or other priority schemes have a large or small effect on the mode splits of peak hour tripmakers has a major impact on the extent of net benefits resulting from HOV lanes and other priority measures. The critical issues for bus rapid transit systems that share highway space with other users thus becomes how the reliability and high speeds that are required by a high-performance bus rapid transit system can best be achieved and maintained, the trade-offs between road capacity and speeds, and the response of tripmakers to the time savings from metering freeways or from the provision of separate bus-HOV facilities. The discussion that follows starts with the first of these issues, how to provide bus rapid transit with the congestion free conditions they require to be effective. This discussion is followed by a review of what is known about the determinants of mode choice, as they apply to transit and carpool use.

Making the "Freeway Fliers" Fly

As Figure 16-2 and the related discussion in Chapter 14 indicate, Meyer, Kain, and Wohl (1962, 1965) in their comparative cost analyses of alternative high-performance urban transportation technologies found the mode they termed "Freeway Fliers" was the most cost-effective method of providing high speed transit services between outlying residential areas and the central areas of large metropolitan areas. Meyer, Kain, and Wohl used the term Freeway Flier's to describe express buses operating on shared, congestion free freeways, or other high performance grade-separated mixed traffic roadways.

While the analyses presented in the Urban Transportation Problem unambiguously showed the superiority of freeway fliers in terms of both cost and performance, Meyer, Kain, and Wohl (1965) were rather vague about how transport planners and policy makers should achieve the required sharing of general purpose facilities and low congestion levels. This is because the problem is as much, if not more, political and institutional as technological. If Meyer, Kain, and Wohl had a preference at the time, it would have presumably been for using tolls to ration roadway space; tolls would simultaneously eliminate congestion and insure that the resulting congestion free road space was allocated to those users, including transit vehicles, which

highly. At the same time, they recognized the deep seated antipathy of commuters, transportation engineers, and policymakers to road pricing, and thus considered various physical restraints, such as ramp metering, which was then being used experimentally on a few urban expressways, as a more promising approach.

Ramp Metering and Bus Bypass

In Congressional testimony and in several subsequent papers, Kain (1970, 1972, and 1973) further developed the idea of implementing bus rapid transit systems by using freeway ramp meters to keep congestion on general purpose freeways at acceptable levels; transit vehicles were to be provided with bus bypasses at heavily used ramps. In his testimony before the Joint Economic Committee, for example, Kain (1970) stated:

> A revolutionary improvement in the quality and quantity of urban transportation services could be obtained in virtually every U.S. metropolitan area in a relatively short period of time. ... These gains could be achieved by converting existing urban expressways to rapid transit facilities through the addition of electronic surveillance, monitoring, and control devices and the provision of priority access for public transit vehicles.
>
> ... there are no technical reasons why freeway rapid transit systems should not have peak-hour speeds equal to or well in excess of those anticipated from any proposed rail rapid transit system ... .
>
> ... these higher potential speeds are less important than the markedly lower capital costs of freeway rapid transit. Because they are able to share costly right-of-way facilities with other users, such systems can be provided at a fraction of the cost of fixed-rail systems. There are no major unsolved technological obstacles. We are prevented from obtaining such systems only by our lack of imagination and unwillingness to overcome existing political and organizational rigidities. Development of these systems requires a complete integration of highway and transit planning and a willingness to impose certain rational restrictions on the use of high-performance urban highway facilities, particularly during peak hours.
>
> Modern limited-access highways move large numbers of vehicles at high speed and with great safety 20 hours a day. However, for 4 hours they are allowed to become so badly congested that vehicle capacity, speed, and safety are seriously reduced. This is inexcusable. The design of these facilities makes it relatively simple to meter vehicles onto the expressway and thereby maintain high performance and high speeds even during peak hours.
>
> If transit vehicles were simply given priority access to these uncongested high-performance highways, they could achieve higher average speeds than private automobiles during peak hours in congested areas. ... Since the new high-performance transit system would be substantially faster and more reliable than existing transit service and would also be considerably cheaper

than private automobile commutation for many workers, significant numbers of automobile commuters might shift from private transportation to the transit system (Kain, 1970, pp. 1142-3).

Using cost estimates developed by Glennon and Stover (1968, 1969) for freeway systems in four representative metropolitan areas, Kain (1970) suggested that necessary modifications in ramp design and required surveillance and control systems could be implemented on most existing urban expressways for $80,000-120,000 per mile (in 1989 dollars); annual operating costs for the surveillance and control systems were estimated at $45,600-$60,800 mile.* Arguing for a large scale demonstration project testing the concept in one or two medium-sized metropolitan areas, Kain suggested the "needed electronics could be installed and the surveillance and control system operated for a five-year demonstration period for between 15 and 30 million dollars (50 and 100 million in 1989 dollars)" (Kain, 1970, p. 1155).**

A Boston Study of Bus Priority Schemes

Kain continued to develop the concept of freeway rapid transit, based on metered ramps and bus bypasses, and as we discussed in Chapter 14, in 1972 he proposed a bus rapid transit system of this kind for Atlanta as an alternative to the far more costly MARTA heavy rail system. Subsequently, Kain and Fauth (1979), using a vest pocket UTPS style model developed by Ingram and Fauth (1974), examined the cost effectiveness of several alternative TSM policies as ways of increasing the productivity of Boston's Southeast Expressway and increasing transit use.

After studying a larger number of expressway management and transit improvement policies, Kain and Fauth (1979) evaluated the six composite policies listed below (all dollar amounts are in 1989 dollars).***

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* These costs estimates were developed as part of an UMTA funded study of freeway rapid transit. As we note in the footnote on Page 10-7 and as Kain indicated in his congressional testimony, the Glennon and Stover study was designed by Kain and Thomas Floyd, director of UMTA's Demonstration Grant Program, when Kain was a consultant to UMTA, which at the time was part of the Department of Housing and Urban Development (Kain, 1970, p. 1143).

All dollar figures are in 1989 dollars, unless noted otherwise. Construction cost figures are adjusted into 1989 dollars using the Engineering News Record Construction Cost Index. All other dollar amounts are indexed using the GNP Implicit Price Deflator.

** Kain (1970, p.1155) added that to "fully test the demand for high-performance transit systems, it might be desirable to provide operating subsidies for saturation transit services throughout the entire region during all or part of the demonstration." He suggested further that a very significant experiment of this kind could be carried out in a middle sized metropolitan area for under $50 million, and noted that while "this is by no means a trivial amount of money, ... it still compares favorably with the one and one-half billion dollar capital cost of the 'BART' experiment."

*** In the process of developing the six composite policies identified above, Fauth and Kain (1979, pp.20-37) also evaluated the impacts and benefits and costs of three Transport System Management (TSM) policies: contra-flow bus-only lanes, concurrent flow bus-only lanes, and ramp metering with a 10 minute delay and a bus bypass, but all without an improved transit system. All three TSM policies provided 45 mph line-haul transit services. For South Shore commuters using the entire length of the Southeast Expressway to reach downtown, the 10 minute delay at on ramps would be only one minute longer than the time savings provided by an increase in AM peak period expressway speeds from 25 mph to 45 mph.

The contraflow lane increase increased South Shore transit use by 10.8 percent and reduced AM peak period vehicle miles of travel on the inbound lanes of the Southeast Expressway by 3.3 percent. The concurrent flow lane increased transit use by 21.8 percent and reduced AM peak period vehicle miles of travel by 24.7 percent, or by about the same amount as the reduction in capacity that resulted from taking away of one of its inbound lanes for use as an exclusive bus lane. Use of a 10 minute ramp meter and bus bypass to ensure the desired 45 mph minimum speed resulted in a 7.6 percent increase in transit ridership and a 17.4 percent decrease in vehicle miles of travel on the freeway. The decline in the number of trips using the Southeast Express-

I-M. Expressway ramp metering with an average delay of nine minutes and an improved transit service charging $0.15 per mile.

I-T. A $1.57 one-way toll with a one-minute average delay, and an improved transit service charging $0.15 per mile.

II-M. Expressway ramp metering with an average delay of 10 minutes and an improved transit service charging $0.17 per mile.

II-T. A $1.77 one-way toll with a one-minute average delay, and an improved transit service charging $0.17 per mile.

III-M. Expressway ramp metering with an average delay of eight minutes, a $1.64 parking surcharge for all central area commuters, and an improved transit service charging $0.15 per mile.

III-T. A $1.38 one-way toll with an average delay of one minute, a $1.64 parking surcharge for all central area commuters, and an improved transit service charging $0.15 per mile.

Table 16-1 provides a summary of the effects of the six composite policies evaluated by Kain and Fauth (1978), relative to a "do-nothing" baseline. The tolls or ramp delays used in the six policies to maintain dependable 35 mph bus speed are paired; I-M (meter) is equivalent to I-T (toll), II-M is equivalent to II-T, and III-M is equivalent to III-T. Composite policy III-T, has the largest net benefits, $72.9 or $85.9 million dollars a year in 1979 (in 1989 dollars).* The two different benefit estimates arise from the use of two different assumptions in costing the improved transit services. The lower benefit estimates assumes the Massachusetts Bay Transit Authority (MBTA) provides these services, while the higher benefit figure assumes that lower cost private carriers would provide them.** The alternative with the second highest net benefit, also uses tolls.

Composite policies that utilize tolls in each instance provide more benefits than otherwise comparable policies that rely on ramp delays to maintain 35 mph speeds on the expressway. The estimates of total annual benefits obtained for the three policies that use tolls to achieve and maintain 45 mph average speeds are more than twice as large on average as the estimates of total benefits for the three paired policies that rely on metering and ramp delays to maintain the desired speeds.

If both CBD parking surcharges and expressway tolls are regarded as politically infeasible, composite policy I-M, which combines an average nine minute delay at expressway on-

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way was much larger than the decline in VMT, indicating that the delays at ramp meters tended to discourage shorter trips from using the expressway.

* Composite policy III-T consists of a $1.64 surcharge on vehicles entering the Boston CBD during peak hours, a $1.38 toll for using the Southeast Expressway, an average delay of one minute for other than transit vehicles at on ramps, and a transit system costing $0.15 per mile.

** At the time of the study, both the MBTA and unsubsidized private carriers were providing peak hour services between the study area and the Boston CBD. In general the MBTA provided service from the more centrally located areas, while private carriers tended to serve the more distant communities.

Table 16–1. Impacts and Benefits and Costs of Alternative TSM and Transit System Policies for Boston's Southeast Expressway (Figures Are All in 1989 Dollars)

Item	Baseline (AM Peak Period)	Changes Relative to Baseline: I–M 9 min delay $.15/mile	II–M 10 min delay $.23/mile	III–M $1.64 Surcharge 10 min delay $.15/mile	I–T $1.57 Toll 1 min delay $.15/mile	II–T $1.77 Toll 1 min delay $.23/mile	III–T $1.64 Surcharge $1.38 Toll 1 min delay $.15/mile
Southeast Expressway							
Number of Vehicles	30,023	(8,948)	(9,222)	(8,977)	(8,948)	(9,222)	(8,977)
Vehicles CBD Cordon	19,458	(3,372)	2,799	(6,431)	(3,372)	2,799	(6,431)
Veh Miles of Travel	174,824	(38,353)	(39,235)	(39,250)	(38,353)	(39,235)	(39,250)
Transit Ridership							
South Shore	8,559	5,090	3,178	5,792	5,090	3,178	5,792
Southeast	29,731	522	599	740	522	599	740
Rest of Region	188,758	396	661	9,211	396	661	9,211
Total Benefits (000's of Dollars)							
Without Transit B&C							
South Shore	NA	$38,665	$15,127	$49,589	$73,617	$55,226	$80,054
Other Corridors						$18,591	$18,591
Total Net Benefits (000's of Dollars)							
MBTA Costs	NA	$12,535	($2,817)	$40,258	$47,488	$37,282	$72,873
Private Carrier Costs	NA	$24,955	$6,697	$55,170	$59,908	$48,508	$85,645

Source: Kain and Fauth (1979).

ramps with a transit system costing seven cents a mile, is the most promising option. For South Shore commuters to the CBD, the travel time savings at 45 mph, as contrasted with 25 mph in the base case, exactly off-set the average nine minute delay at freeway on-ramps. As the estimates in Table 16-1 indicate, the net benefits from policy I-M are less than half as large as if a CBD surcharge could be used (Policy III-M), and less than a third as large as if both a CBD surcharge and expressway tolls could be used (Policy III-T). Kain and Fauth (1979, pp. 79-80) present the following general observations about the advantages of using ramp meters to provide bus priority:

> The alternatives we tested are a contra-flow lane, a concurrent-flow lane, metering of expressway on-ramps, charging of tolls, and surcharges on central area parking. All of the policies could be used to insure express buses dependable 45 mph speeds on expressways serving the Southeast Corridor. Our analyses clearly indicate that either expressway metering or tolls are the preferred techniques to achieve the desired roadway conditions; some form of central area auto restraint would also increase the effectiveness of these policies.
>
> The principal advantage of ramp metering or tolls as compared to either of the reserved lane policies is that none of the expressway's valuable capacity is wasted. Ramp delays or tolls can be set to allow as many vehicles on the road as can be accommodated at a predetermined speed.

Small's Study for the Bay Area

The Kain-Fauth (1979) finding that tolls are a superior way of achieving and maintaining the high speeds and reliability required for high-performance bus operations is confirmed by a similar analysis by Small (1983). Small analyzes the benefits and costs that would arise from implementing various bus priority schemes on expressways in the San Francisco Bay Area. Comparing the use of marginal cost pricing of the entire freeway to bus priority achieved through the provision of a bus-carpool lane, Small (1983, p. 57) finds that, "bus priority achieves slightly less than half the mode shift produced by pricing, about one-third the travel-time savings for autos, and slightly more than half the benefits."

In the alternative that most closely approximates the one studied by Kain and Fauth (1979), Small (1983) found that implementing a bus-carpool lane would reduce auto travel time by 5.6 minutes per trip and bus travel time by 14.9 minutes per trip, relative to a baseline case where no bus-carpool priority was provided. In the base case, the average auto trip took 32.5 minutes and the average bus in-vehicle time was 49 minutes. Small finds, moreover, that bus priority provides direct benefits, in 1989 dollars, to commuters of $1.25 per trip, relative to the base case.* Somewhat surprisingly, Small finds that the benefits from a priority lane would be nearly as large if priority was given to, say, red cars, as to carpools. This is because, at least in

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* The magnitudes of time savings and benefits per trip depend on demand, which is exogenous in Small's model. He presents calculations for two levels of demand, 3,160 passengers per hour per lane and 3,580 passengers per hour per lane. The numbers reported above are for the higher figure, which he apparently regards as the more relevant case since he uses it for his sensitivity analyses. If demand is 3,160 passengers per hour per lane the travel time savings per trip are 2.1 minutes for autos and 5.9 for buses. Direct benefits with this demand assumption become 47 cents per passenger trip (in 1989 dollars).

the particular situation Small studied, giving carpools priority did not induce much carpooling. Thus, most of the benefits from allowing carpools to share the HOV lane with buses were the result of more fully utilizing the priority lane's capacity.

Small (1983, p. 68) offers the following general observations about the benefits of priority lanes and the efficacy of such policies relative to road pricing.

> First, are the potential benefits from bus priority substantial? The answer is clearly "yes... ." The divisible bus priority scheme produces direct benefits of 34-91 cents per passenger-round trip ($.93-2.58 in 1989 dollars) when initial congestion is from 6 to 15 minutes of one-way queueing delay. This represents direct benefits on an express-way with three lanes in each direction of approximately $1.6 million to $5.0 million per year ($4.4 to 13.7 million in 1989 dollars). ... annual capital cost plus maintenance costs for such a system might be in the order of $12,000 ($33,000 in 1989 dollars), orders of magnitude below our benefit estimate.
>
> Second is bus priority a satisfactory substitute for short-run marginal cost pricing? The answer is that, under idealized conditions in which lane capacities can be allocated in arbitrary fractions without waste, bus priority is a half-way measure: It achieves roughly half the modal shifts, travel time savings, and benefits of marginal cost pricing. The distribution of benefits is quite different, however: Marginal cost pricing produces large benefits in the form of toll revenues, but those accruing directly to individuals are smaller than with bus priority and many may even be slightly negative for the lower-income classes. To the extent that people do not perceive benefits accruing to the government as real, it is not difficult to understand the greater popularity of priority systems.

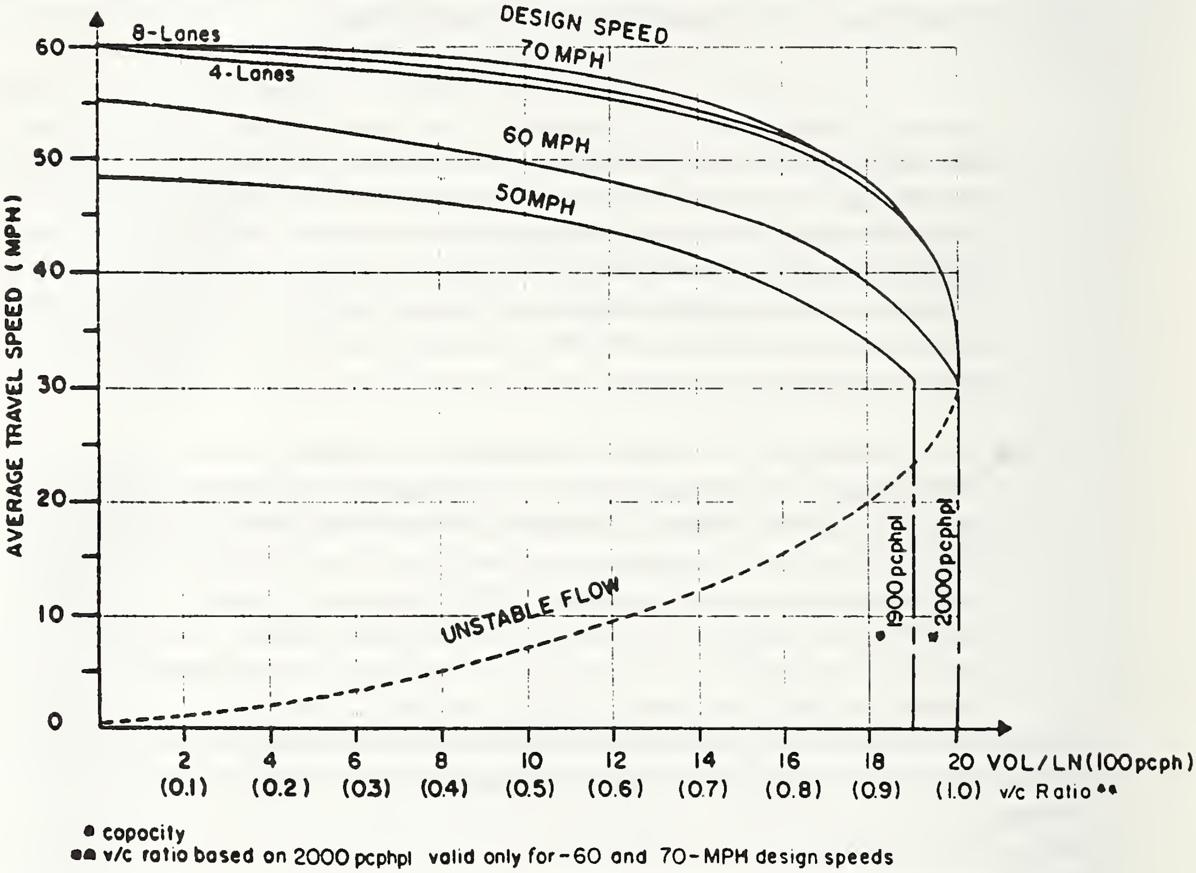
The Gains from Separate Bus-Carpool Lanes

Transport engineers and planners in a growing number of metropolitan areas are using ramp meters to increase the capacity of urban expressways, and, perhaps, more importantly, to reduce the frequency of situations where "oversaturation" leads to a grossly inefficient movement of vehicles during peak hour periods. When such conditions arise, as they all too often do on uncontrolled, heavily congested urban expressways, both speeds and vehicular throughput decline. In situations where bus volumes are heavy, those responsible for designing and managing urban freeways have increasingly provided bus or bus/carpool bypasses at metered ramps. As we discussed in Chapters 2 and 9, Los Angeles and Seattle have been among the leaders in implementing these technologies.

In spite of the growing use of ramp meters to manage urban expressways, highway and traffic engineers have shown a clear preference for separate bus/carpool lanes to provide high-speed and dependable bus transit services on urban expressways, rather than ramp metering.* One reason is undoubtedly the problem of enforcing compliance with ramp meters when queues

* Small (1983, p. 28) credits an article by Morin and Reagan (1969) for helping to persuade highway and traffic engineers to use carpools as a way of reducing the underutilization problem associated with exclusive bus lanes on urban expressways.

Figure 16-1. Representative Speed-Volume Relationship for High Performance Urban Expressways



Source: TRB (1985, p.3-40).

and ramp delays become long and when the freeway has the visual appearance of being under-utilized, which it does at volume levels that would insure dependable 50-55 mph speeds for transit vehicles. Kain's proposal to meter entire freeways is an alternative approach to avoiding the waste inherent in allocating an entire lane to buses, which in most situations in North America require no more than 5-10 percent of a single lane's capacity.

Even if the managers of controlled, i.e. metered, urban expressways wanted to maximize total user benefits for a particularly highway, which would be approximately equal to the number of person trips carried per hour, and even if enforcement was not a problem, they would be faced with a hard policy choice. As Figure 16-1 indicates, average travel speeds decline fairly slowly as vehicle volumes (measured in passenger car units or PCUs) increase, until about 1,400 to 1,600 PCUs per hour, and then decrease at a much more rapid rate until the freeway's capac-

ity is reached at about 1,900 to 2,000 PCUs, per hour, per lane.* At this point, traffic becomes unstable and efforts to crowd more vehicles onto the road can lead to oversaturated conditions. When such oversaturated conditions occur, both speeds and vehicular capacity decline. The interest of highway engineers in metering is due principally to their interest in avoiding the wasteful reductions in freeway capacity and speeds that occur when volumes are allowed to reach the point that the unstable flow situation, illustrated by the backward bending (dashed line) part of the speed volume relationship in Figure 16-1.

Illustrative calculations suggest that separate bus-carpool lanes may be a more cost effective method of providing high performance transit on shared high performance roadways than metering in many situations. Shown in Table 16-2 are the numbers of peak-hour vehicle and person trips that could be accommodated in the space required for an eight-lane (two-direction) urban freeway for various ways of configuring and using the right-of-way. The resulting estimates of the number of bus, carpool, and low occupancy vehicle (LOV) vehicle and person trips are meant to crudely represent the conditions and trade-offs that exist for radial freeways in large metropolitan areas. As we discuss in greater detail at a later point in this chapter, the actual numbers of LOV, carpool, and bus vehicle and person trips will vary from place to place and depend on the response of tripmakers to the time savings afforded by metering or HOV lanes. We have tried to use representative numbers, but the results shown should be viewed as suggestive, rather than as precise, measures of the impacts of the configurations/policies shown on peak hour person and vehicle trips.

The first two rows in Table 16-2 give peak hour, peak direction vehicle and person trip volumes for two base cases which assume unrestricted use of an eight lane freeway. In the first case, the freeway is assumed to operate at 30 mph and to serve about 8,000 vehicle and 10,000 person trips during the peak hour in the peak direction. This case, which represents the maximum vehicular flow that can be achieved, assumes a capacity of 2,000 passenger cars per hour, per lane (or PCPHPL) for the freeway; that average vehicle occupancy is 1.15 persons per vehicle for LOVs, 3.25 persons per vehicle for 3+ carpools, and 35 persons per vehicle for buses; and that the 30 mph and 2,000 PCPHPL flow can be maintained without experiencing the unstable flow conditions that reduce both speeds and capacity. The second case is identical to the first, except that demand is less (1,400 PCPHPL), and, as a result, average speeds are 55 mph. Under these assumptions, the freeway carries about 7,200 persons per hour in the peak direction during the peak hour.

The third example in Table 16-2 assumes the freeway right-of-way is configured as three general purpose traffic lanes and an exclusive bus lane. Converting one of the four general purpose traffic lanes to an the exclusive busway decreases the number of vehicles carried by about 23 percent, but increases the number of persons carried by 12 percent relative to the base case, i.e. four general purpose traffic lanes and 30 mph.

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* The curve shown in Figure 16-1 is a representative speed volume relationship obtained from the Highway Capacity Manual (TRB, 1985). It illustrates the relationship between average speed and hourly volumes for high-performance (60-70 mph design speeds) urban expressways under ideal conditions. The true relationship will vary from one facility to another and from one part of the same facility to another. In addition, there are clearly situations where the speed volume relationship is better modeled as a bottleneck, and where travel times are better represented by a deterministic queuing model (Small, 1983, p. 32). In either case, when traffic volumes are low, small reductions in the numbers of vehicles using the facility do not affect traffic speeds greatly, but when traffic volumes are high, small reductions result in large improvements in travel speeds.

Table 16–2. Alternative Freeway and Bus–HOV Management Policies for Four Lane Urban Expressways

	Speed		Vehicles/Lane GP FHWY Lane			Vehicles Bus/3+CP Lane		Persons/Lane		Entire Facility	
Type and Policy	GPL	HOV	LOV's	3+CP	Bus	3+CP	Bus	GPL	HOV	Vehicles	Persons
4 GP Lanes	30	NA	1,980	12	5	NA	NA	2,491	NA	7,988	9,964
4 GP Lanes	55	NA	1,379	13	5	NA	NA	1,803	NA	5,588	7,212
3 GPL & 1 Buslane	30	55	1,987	13	0	NA	120	2,327	4,200	6,120	11,182
Metering											
4 Lanes Bus B/P	45	45	1,750	15	22	NA	NA	2,831	NA	7,147	11,324
4 Lanes B&CP B/P	45	45	1,716	50	21	NA	NA	2,871	NA	7,150	11,485
4 Lanes Bus B/P	55	55	1,336	16	30	NA	NA	2,638	NA	5,528	10,554
4 Lanes B&CP B/P	55	55	1,279	75	29	NA	NA	2,729	NA	5,530	10,917
3 GPL & 1 HOV	30	55	2,000	0	0	700	100	2,300	5,775	6,800	12,675

Notes: (1) Person Trips/Bus: 35
(2) Persons/3+CP: 3.25
(3) Persons/LOV: 1.15
(4) Capacity/Lane: 2,000 PCU/Hr
(5) B/P = Ramp Bypass

The next four rows present illustrative calculations for four policies that employ ramp metering and HOV bypasses. The first two metering cases assume speeds average 45 mph (1,800 PCPHPL), while the second two assume speeds average 55 mph (1,400 PCPHPL).* In addition, the first and third cases assume that only buses are allowed to use the ramp bypasses, while the second and third cases assume both buses and 3+ carpools are allowed to use them. All four metering policies serve more person trips than the base case, and the first two (45 mph freeway speeds) outperform the exclusive buslane.** The third and fourth metering schemes (55 mph freeway speeds) also outperform the base case, but they do less well than the exclusive busway. The reason is that they attract about the same number of bus riders, but accommodate somewhat fewer auto users.

The final case, the lightly shaded bottom row in Table 16-2, is representative of the kind of scheme that has emerged as the preferred approach to providing bus and carpool priority. In this case three lanes are operated as general purpose freeways, managed so as to maintain

* Kain (1970, 1972, and 1973), in proposing the use of ramp meters to create an environment for bus rapid transit, envisioned operating urban expressways at average speeds of 50-55 mph. Similarly, as we report in Chapter 10, Houston METRO uses a 55 mph target speed for their transitways, and in the case of the Katy Transitway, at least, changed the carpool criterion from 2+ to 3+ during the AM peak period to maintain this standard. As we also discuss briefly in Chapter 10, Robert C. Lanier, Chairman of METRO's board at the time, ignored the advice of the Texas Transportation Institute's (TTI's) staff in making the decision to change the AM peak period carpool criterion from 2+ to 3+. The TTI staff, at the time, favored a higher vehicle volume and lower speed, closer to 35 mph than the 55 mph that METRO had previously set as its standard for its transitways. This is consistent with the practice of highway engineers generally, who, with a few notable exceptions, have tended to be guided by the principal of vehicle flow maximization rather than person flow maximization in designing and operating urban freeways.

** In their Boston, Southeast Corridor study of ramp metering and tolls, Kain and Fauth (1979), after some experimentation, chose 45 mph as the target speed for freeway operations.

speeds in the 30 mph range and volumes that are as close to capacity as can be achieved without encountering destructive instability. The fourth lane is managed as a bus-vanpool-carpool lane with a 55 mph target speed and volumes in the 1,400 PCU per hour range. As the data in Table 16-2 indicate, this mixed strategy serves more peak hour person trips than any of the other policies, while accommodating 85 percent as many vehicles as when all four lanes are used as general purpose freeway lanes at volumes that maximize vehicular flow. Not too much should be made of the comparisons in Table 16-2, however, except for illustrating the nature of the trade-offs involved. The estimated number of persons served in each configuration/policy depends on critical assumptions about bus ridership and carpool use and the effect of travel time savings on these choices. We have made an effort to incorporate the findings of several relevant studies in formulating these assumptions, but there remains a great deal of uncertainty.*

Bus Carpool Lanes and Mode Choice

As we discussed briefly in Chapter 2, there remains considerable skepticism about the advantages and disadvantages of bus-carpool lanes. A San Francisco Examiner story by John Finn (1988) titled "Diamond Lanes Run Into Roadblocks," for example, states that "critics complain that the lanes create 'artificial gridlock' by reserving 25 or 33 percent of freeway space for only nine percent of the traffic." The same article refers to a study by a citizens group, Drivers for Highway Safety. which claims that the carpool lanes on the Costa Mesa freeway "actually decreased the road's carrying capacity by 12 percent."

It is impossible to evaluate the merit of these arguments without more information about the facilities in question. They may simply reflect the inability or unwillingness of critics to correctly measure benefits in terms of person, rather than vehicle, capacity. At the same time, bus-carpool lanes can be wasteful in some situations. If relatively few carpools and buses use the lanes, they may provide fewer benefits than when the lane is simply used as another general purpose traffic lane.

Whether the benefits of a particular HOV facility are greater than its costs, where costs include the opportunity cost of using the lane as a general purpose freeway lane, will depend on the number and types of vehicles using it. The aggregate time savings provided by a particular HOV lane increase as the fraction of tripmakers that use modes of travel that make more efficient use of road space, i.e. buses, vanpools, and carpools increases. While the net benefits of bus-carpool lanes may still be positive, even if they merely shift buses and large numbers of carpools from general traffic lanes to a priority lane, the net benefits will be much greater if large numbers of automobile commuters shift to buses or carpools. The effect of the time savings provided by bus-carpool lanes on transit and carpool modal shares is thus a critical issue. Similarly, as we pointed out previously, assumptions about the response of tripmakers to the time savings pro-

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* In developing the estimates in Table 16-2, we tried to informally incorporate the findings of simulation studies by Kain and Fauth (1979), by Small (1983), and the analyses of HOV facilities by Parody (1982 and 1983) and Ulberg (1987). The preferred approach, the construction of a simulation model similar to those used by Kain and Fauth (1979) and Small (1983), was simply beyond the scope of this study. In addition, the result would still depend critically on assumptions about the determinants of mode choice that are still subject to a great deal of uncertainty and a variety of specific factors that would vary from one area or corridor to another.

vided by ramp metering - bus/carpool bypasses or HOV lanes are central to the rankings of alternative freeway configurations-policies shown in Table 16-2.

Small (1983) in his analysis of priority schemes for Bay Area expressways considers both bus and carpool measures.* To illustrate the effects of priority schemes on transit ridership and carpooling, he examines the effects of a priority scheme which confers a 24-minute round-trip time advantage on priority vehicles. Using a multinomial logit model estimated from Bay Area data, Small (1983, p.52) finds that if "carpools are not included, bus patronage increases by 25 percent and both forms of auto travel decline, resulting in a 7.5 percent reduction in traffic.** If carpools also receive the time advantage, bus patronage increases by only 19 percent; but carpooling rises by 29 percent, resulting in an even larger reduction (9.5 percent) in traffic." While we know of no formal analysis of the impacts of opening of the El Monte Busway to 3+ carpools, the experience (see Chapter 8) appears to be broadly consistent with Small's findings for the Bay Area.

In addition to estimates of time and cost, the Bay Area mode choice model also includes a "carpool dummy" variable, which Small (1983, p. 47) interprets as "the free estimation of a penalty attached to carpooling relative to noncarpool auto." He adds that it lumps the additional in-vehicle time required for carpooling together with any other undesirable features, such as scheduling inconvenience" and finds that the resulting estimate implies, "that, other things being equal, that this extra time plus inconvenience is worth 100 minutes of in-vehicle time for a typical commuter!" He is quick to point out, however, that everything is not equal because costs are shared by 3.52 instead of 1.11 individuals. Even so, Small (1983, p 48) concludes that "carpooling will have a low probability for most individuals; in practice, it probably depends largely on the chance of matching schedules of family members or neighbors."

Small's model is one of a relatively small number of mode choice models that include carpools in their choice set. The failure of most mode choice models to include carpools is explained in part by the general neglect of carpool priority policies, and in part by the fact that carpooling is inherently difficult to analyze, to include in modal split models, and to forecast, even if an appropriate disaggregate mode choice model is available.***

An alternative approach to determining how the time savings provided by bus-HOV lanes affect the extent of transit use and carpooling has been to analyze the ridership and mode choice changes that occur when a new bus-HOV facility is implemented or when the criteria governing the use of an existing HOV facility are changed, e.g., allowing carpools to use what was previously a bus only facility or changing the carpool criteria from 3+ to 2+, or the opposite.

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* The ramp metering/bus bypass policies analyzed by Kain and Fauth did not give priority to carpools. Thus, the estimated impacts of the policies tested on auto use and aggregate net benefits are presumably smaller than if carpools had been included. At the same time, the projected increases in transit ridership and reductions in auto use were also due in part to the provision of improved transit services to South Shore communities.

** The multinomial logit, mode choice model used by Small in his analysis was estimated using 1972 data for 213 San Francisco Bay Area commuters. The sample consists of residents of a Y-shaped area in the East Bay which forms the catchment for both the Bay Area Rapid Transit (BART) system, under construction at the time, and for the major freeway corridors.

*** The principal problem both in specifying and estimating mode choice models and in using such models to predict carpool use is the conceptual and measurement problems of accounting for the circuity and other costs associated with forming carpools.

A closely related approach compares transit and carpool use on facilities with bus-HOV lanes to their use on comparable facilities without HOV lanes. Both types of analyses have flaws.

In the first kind of study, the most serious of several methodological problems is the difficulty, if not the impossibility, of accounting for "other" factors that may have changed at the same time the HOV was implemented, or policy changes governing the lane's use were made. The second kind of study confronts the nearly impossible task of accounting for differences between one freeway or freeway corridor and another. Still another important problem associated with both kinds of study is the difficulty of distinguishing between net increases in transit use and carpooling that result from HOV lane travel time savings, and the shift of pre-existing transit users and carpools from general purpose freeway lanes and from routes that are parallel to the newly introduced or modified HOV lane. The econometrically estimated mode choice models discussed briefly above largely avoid these problems, but they are beset by others. In addition, as we mentioned previously there have been very few careful econometric studies of mode choice that have included carpools in an acceptable way.

The most ambitious before and after analysis of the effects of new or modified bus-HOV lanes on transit use and carpooling is a study by Parody (1982, 1983) of 12 freeway HOV facilities/eligibility changes (or phases). Relying on the data in Table 16-3, Parody estimates regression equations that explain the percentage change in nonpriority auto trips in the general purpose freeway lanes, the percentage change in priority autos (2+ or 3+ carpools) on the freeway, and the percentage change in transit ridership in terms of percentage changes in travel times for priority and non-priority vehicles. An otherwise fine study, is flawed by the fact that the estimates are based on only 12 observations. Nonetheless, Parody used data for all, or at least nearly all, of the HOV facilities that had been implemented at the time he carried out his study, and his results are generally plausible. In addition, Parody's models have been used with some success in at least one cost-effectiveness analysis of HOV facilities (Ulberg, 1987).

The specifications used by Parody require some explanation. All three bus models use the percentage change in bus person trips as their dependent variable, while the carpool and nonpriority auto models both use the percentage change in vehicles. Parody uses vehicles in his carpool and nonpriority auto equations because the predicted changes in vehicles per hour are used as inputs to a highway supply model, which, in turn, is used to calculate nonpriority auto speeds.

As is evident from Table 16-4, Parody estimated three separate bus models. The first bus model, which includes only one explanatory variable, the percentage change in bus travel times, indicates that a one percent decrease in bus travel times, resulting from the implementation of bus priority, would increase bus ridership by 1.4 percent.* The principal problem with the specification Parody used for the first bus model is that, as we discussed in earlier chapters, the opening of a new busway or a bus-HOV facility is often accompanied by substantial increases in the coverage and frequency of corridor bus service. The second bus model represents a crude effort to control for the effects of such exogenous (policy) increases in bus service. Including the

* In defending this sparse specification, Parody (1982, p. 63) notes that, "what the estimation process revealed was that other factors, such as changes in nonpriority auto travel time, or even secular transit growth rates (which show up in a constant term) have little or no explanatory power compared to bus travel time changes." He adds that because of the small sample size, the coefficient estimate for the percentage change in bus travel times is not very significant statistically.

Table 16–3. Summary of Key Data for Freeway HOV Sites

HOV Facility	Priority Auto Volume (veh./hr.) Before	Priority Auto Volume (veh./hr.) After	Transit Riders/hr. Before	Transit Riders/hr. After	Avg. Travel Time by Lane (min) General Purpose Before	General Purpose After	HOV Before	HOV After	Change in IVT (min) Nonpri.	Change in IVT (min) Priority	Buses/hr. Before	Buses/hr. After	HOV Treatment Before	HOV Treatment After
Shirley Highway	195	758	7,900	8,756	56.2	58.3	37.5	38.3	2.1	−17.9	176	194	Bus	4+ C
										0.8 (a)				
San Bernardino														
Phase 1	NPA	NPA	402	1,017	44.8	45.3	NPL	36.9	0.5	−7.9	10	45	NP	Bus
Phase 2	299	576	2,490	2,708	45.7	46.1	34	35.3	0.4	−10.4	81	81	Bus	3+ C
								34 (a)						
US–101														
Phase 1	NPA	NPA	3,370	3,572	35	35	NPL	32.2	0	−2.8	86	94	NP	Bus
Phase 2	205	288	3,572	3,686	35	33.1	32.2	32.2	−1.9	−2.8	94	97	Bus	3+ C
Banfield Freeway														
Phase 1	37	180	340	570	21.1	21.1	NPL	19.7	0	−1.4	10	20	NP	3+ C, B
Phase 2	530	1,107	628	657	22.7	21.4	20.9	20.9	−1.3	−1.8	20	22	B, 3+ C	2+ C
	178 (b)	163 (b)												
I–95, Miami														
Phase 1	170	309	274	314	36.9	34.5	33.4	31.3	−2.4	−5.6	10	10	Bus	B, 3+ C
								32.9 (a)		0.5 (a)				
Phase 2	1,246	1,357	314	352	34.5	34.7	31.3	31.3	0.2	−3.2	10	10	B, 3+ C	2+ C
	309 (b)	246 (b)					32.9 (a)	32.9 (a)						
Southeast Expressway														
1977	388	641	2,000	2,124	35	43	NPL	25	8	10	50	54	NP	B, 3+ C
1971	NPA	NPA	2,152	2,454	35	30.5	NPL	23	−4.5	−12	57	65	NP	Bus
I–45, Lincoln Tunnel	NPA	NPA	21,868	26,092	70	68	NPL	60	−2	−10	497	597	NP	Bus

Note: NPA = no priority automobiles included in HOV treatment; NPL = no priority lane; NP = no priority; Bus = bus only; B = bus; C = carpool or vanpool; IVT = in vehicle time.
(a) priority automobile or priority bus; (b) two–occupant or three–occupant carpool.

Source: Parody (1982, 1983).

Table 16–4. Bus, Carpool, and Non–priority Auto Demand Models for Bus–HOV Facilities

	Carpool Model		Bus Only (Endogenous)		Bus Only (Exogenous)		Bus plus CP		Nonpriority Model	
	Coef.	T	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Dependent Variable	Veh/hr	–	Psgr/hr	–	Psgr/hr	–	Psgr/hr	–	Veh/hr	–
Constant	–0.20	–0.6	–	–	–	–	0.227	1.2	–0.916	–10.5
Percentage Change in:										
2+CP Travel Time	–6.70	–1.3	–	–	–	–	0.435	0.5	1.190	3.5
3+CP Travel Time	–7.70	–4.1	–	–	–	–	1.710	0.5	0.122	1.4
Bus Travel Time	4.80	2.3	–1.404	–1.1	–0.308	–2.3	–	–	0.278	3.8
Peak Hour Buses	–	–	–	–	0.422	26.7	–	–	–	–
NPA Travel Time	–	–	–	–	–	–	–	–	–1.053	–3.3
Eligibility Factor	–	–	–	–	–	–	–	–	0.949	12.1
R2	0.87	–	0.28	–	0.99	–	0.44	–	0.98	–

Notes: (1) NPA is nonpriority auto.
(2) Eligibility Factor is a measure of the percentage change in capacity on the general purpose lanes made available in the after period for use by nonpriority autos. It accounts for the taking away of lanes and the movement of vehicles that were previously using the general purpose lanes to the HOV lanes.

Source: Parody (1982, 1983).

percentage change in peak hour bus (vehicle) trips dramatically decreases (in absolute value) the bus travel time coefficient (elasticity); it becomes a more plausible -0.308, indicating that a one percent decrease in bus travel times would increase bus ridership by about 0.3 percent. Each one percent increase in per hour bus trips, moreover, increases bus ridership by 0.42 percent. As the R^2's and t-statistics in Table 16-4 indicate, moreover, adding a bus supply variable to the model both boosts the models overall explanatory power, and increases the t ratios for the bus travel time variable from only -1.1 to a respectable -2.3. The coefficient of the bus supply variable has a t-ratio of 26.7.

The third bus model in Table 16-4 is used to predict changes in bus ridership in situations where carpools are allowed to use what was previously an exclusive busway. The impact of such a change on bus ridership obviously depends on whether 2+ carpools are allowed to use the facility or whether its use is limited to 3+ carpools.* Unfortunately, the test statistics for the bus plus carpool equation indicate this model is not very reliable. The R^2 and t statistics are quite low and the magnitudes of the 2+ and 3+ carpool travel time coefficients imply the implausible result that opening an exclusive busway to 2+ carpools would have had a smaller impact on bus ridership than if eligibility had been limited to 3+ carpools.

* The coefficient for 2+ carpools indicates that when a facility is opened to 2+ carpools, each one percent decrease in the travel times of priority 2+ carpools will cause bus ridership to decline by 0.4 percent. The 2+ carpool coefficient is not used when 3+ carpools are allowed to use the facility; instead the 3+ carpool coefficient is used. Use of the 3+ carpool coefficient causes bus ridership to decrease by 1.7 percent for each one percent decrease in the travel times of 3+ carpools.

Parody's carpool model suggests that decreases in carpool travel times, resulting from opening bus-HOV lanes to carpools, would lead to large percentage increases in the numbers of carpools using the freeway. It should be emphasized, however, that not all of this growth in carpools represents new carpools; an unknown fraction are pre-existing carpools diverted from other routes. In addition, the t statistics are vanishingly small, indicating that very little, if any, attention should be paid to the carpool travel time coefficients. The percent change in the bus travel time variable, which indicates that each one percent decrease in bus travel times would reduce carpools by 4.8 percent, exhibits more statistical significance, but the effect is implausibly large.

The final equation in Table 16-4 provides predictions of the percentage change in nonpriority vehicles, i.e. vehicles using the non-priority lanes. All five explanatory variables have the correct signs and the equation as a whole explains 98 percent of the variance of the percentage change in nonpriority vehicle use. In addition, the coefficients for percentage changes in 2+ carpool and nonpriority auto travel times, which are 1.2 and -1.1 respectively, have relatively large t ratios, even though they are estimated with only seven degrees of freedom.*

While Parody deserves praise for his ingenious efforts to learn from the limited experience available at that time he completed his study about the effects of new bus-HOV lanes or changes in occupancy criteria, and while his results are generally plausible, they are also based on only 12 observations. As the number of bus-HOV facilities increases and/or as the criteria governing existing ones are changed, there is a strong argument for redoing Parody's study. Additional observations should be added to Parody's sample and his equations, or improved ones, should be estimated in an effort to improve our all too limited understanding of how bus and carpool priority schemes affect bus and carpool use.

As we discussed in Chapter 10 the ongoing implementation of Houston's transitway system provides some of the best information about the impacts of bus-HOV priority schemes on both transitway demand and on travel demand more generally. Somewhat surprisingly, transportation planners in Houston have not taken advantage of the growing experience provided by Houston's increasingly rich range of transit, vanpool, and carpooling choices to estimate a state of the art mode choice model.** The Texas Transportation Institute (TTI), however, has completed a number of analysis of the effects of the transitways on travel in Houston; the results of some of these analyses, which are similar in spirit to Parody's before and after study of HOV lanes are discussed in Chapter 10. Other findings are reported briefly below.

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* A so-called eligibility factor is quantitatively the most important variable and the one with the largest t ratio. It accounts for both decreases in the highway capacity available to nonpriority autos that are caused by taking away a general traffic lane and increases in capacity that result from the shift of buses and carpools that had previously used the general traffic lanes to the HOV lane.

** As part of its most recent effort to develop an acceptable rail plan for Houston), METRO (Houston's regional transit authority) is apparently planning to hire COMSIS Corporation to develop a new synthetic mode choice model for Houston. It is our understanding that the current plan is to port parameters from a multinomial logit mode choice model COMSIS Corporation (1989) recently estimated using Shirley Highway data to Houston, and to use various local data, particularly the 1985 bus trip table that was used in developing the CRA incremental forecasting model for METRO's recent rail research study, to calculate a Houston model. This effort will most likely result in a better mode choice than the one METRO has been using, which cannot predict carpool use and which was developed using mode choice model parameters ported from a 1972 Minneapolis-St. Paul mode choice model, but it is also presumably much inferior to one that could be estimated for Houston from a carpool sample survey representing the rich and rather unusual choice set available to Houston residents.

Christiansen and Morris (1989) in a recent paper on the status and effectiveness of Houston's transitways make the following observations:

> Provision of travel time savings is perhaps the most important single factor influencing transitway use. Quite simply, unless severe freeway congestion exists, usage of transitways will not be high. It has been postulated for several years that a priority high-occupancy vehicle lane must provide at least one minute of travel time savings per mile of lane to be successful (Baught, 1979). The Houston data ... suggest that unless the transitway offers a travel time savings in excess of 7 to 8 minutes during the peak hour, utilization of the transitway will be marginal.*

In support of their conclusions, given above, Christiansen and Morris (1989) offer the freehand fit curve, shown in Figure 16-2, which relates average peak-hour transitway ridership to average transitway peak-hour savings (relative to the general purpose freeway lanes).

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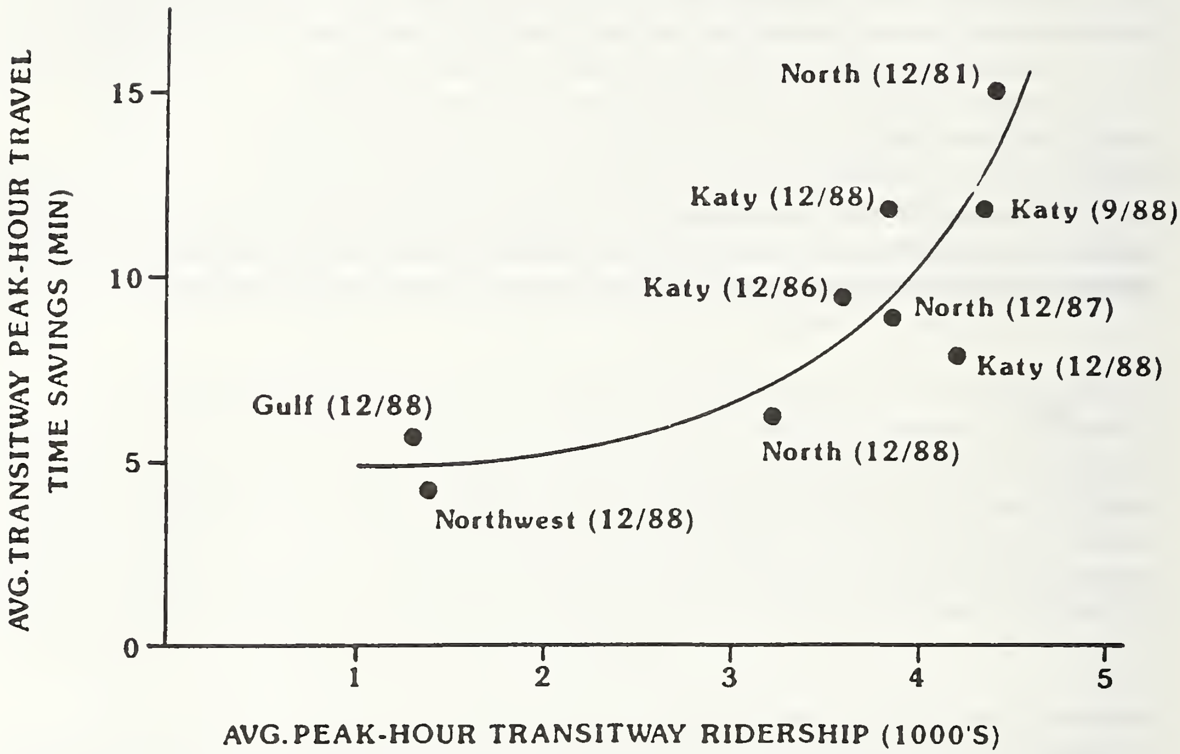
* Christiansen and Morris (1989, pp. 18-19) add the following comments about the relationship between transitway use and improvements in the regions road system, and about the incomplete nature of some of the existing operational transitway segments:.

> This conclusion currently impacts several of the Houston freeway transitways. The completion of the North Freeway widening between I-610 and North Shepherd, combined with the opening of the Hardy Toll Road, have at least temporarily reduced travel time savings in that corridor. When the contraflow lane first opened in 1979, 15-minute travel time savings to contraflow lane users were typical; the corresponding time savings were closer to 6 minutes in 1988. The section of the Gulf Transitway currently in operation is located in a freeway segment that has recently been significantly expanded. The transitway currently offers peak-hour travel time savings of about 5 minutes; this marginal level of travel time savings will continue at least until the second phase of the transitway is completed. And, while 9.5 miles of the Northwest Transitway are operational, the geometrics and operations at the temporary terminus of this lane at West Little York cause severe congestion for transitway users. In fact, in the afternoon, travel time savings generated by the transitway are more than negated by the congestion experienced at the terminus of the transitway. Completion of the transitway, scheduled for 1989, should eliminate this problem and result in an increase in transitway utilization; until that occurs, marginal peak-hour travel time savings of about 4 to 5 minutes will continue to exist.

Figure 16-2. Average Peak Hour Transit Ridership vs. Average Peak Hour Savings for Houston Transitways at Various Points in Time



Note: Travel Time Savings and Ridership are averages for the AM and PM Peak Hours. Data for Katy in 9/88 Reflect use by 2+ Vehicles; 12/88 Data Reflect Change to 3+ Requirement from 6:45 a.m. to 8:15 a.m.

Source: Christiansen and Morris (1989, p.19).

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